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DENTAL MICROWEAR AND STABLE ISOTOPE ANALYSES AS INDICATORS OF
CHANGES IN SUBSISTENCE PRACTICES DURING THE SPANISH COLONIAL PERIOD
IN THE LAMBAYEQUE VALLEY REGION OF NORTHERN PERU

by

TRACE BROOKS

Under the Direction of Bethany L. Turner

ABSTRACT

This study utilizes stable isotope and dental microwear analyses to elucidate diet and subsistence practices of indigenous Muchik peoples interred at two sites in the Lambayeque region of northern Peru: La Capilla Santa María Magdalena De Eten (CSMME) (n=17) and La Capilla Del Niño Serranito (CNS) (n=18). Burials at CNS date to the Early Colonial Period (A.D. 1533-1620), while burials at CSMME date to the Mid- to Late-Colonial Period (A.D. 1625-1760). Dental microwear and stable isotope investigations reveal a highly correlated dietary profile across both sites, which suggests consistent subsistence practices across the Colonial Period, insofar as can be measured using these techniques. However, there is significant differences between CNS and CSMME in dental microwear features indicating the foods consumed by all members at each site—since sex and age are not significantly different between the two sites—is perhaps attributable to the influence of Spanish colonial rule to the degree to which these dental microwear features capture larger patterns in these two populations. Although samples sizes are limited, at CNS, the frequency of fine scratches and small pits increase with age and coarse scratches decrease between childhood and adolescence, indicative of transitions in diet or the use of the teeth during the maturation. Further, statistical inquiry found no significant dental microwear differences between site, age, or sex in the studied populations.

INDEX WORDS: Spanish Contact; Bioarchaeology; Stable Isotope Analysis; Dental Microwear;
Dietary Reconstruction; Dietary Life History; Peru; Lambayeque

DIETARY LIFE HISTORY AS AN INDICATOR OF CHANGES IN SUBSISTENCE
PRACTICES DURING SPANISH CONTACT IN THE LAMBAYEQUE VALLEY REGION OF
NORTHERN PERU

by

TRACE BROOKS

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Arts

in the College of Arts and Sciences

Georgia State University

2016

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS-----	7
LIST OF TABLES -----	11
LIST OF FIGURES -----	12
CHAPTER 1: STUDY INTRODUCTION-----	13
1.1 Introduction-----	13
1.2 A Brief History of Eten -----	13
Figure 1. Archaeological sites and physical features of the Lambayeque Valley; Eten highlighted. (Klaus and Alvarez-Calderon, in press). -----	15
1.3 Purpose of this Study-----	16
1.4 Expected Results-----	17
1.5 Contributions to Contemporary Understanding -----	18
1.6 Contact Period Peru: Balancing Historical and Archaeological Accounts -----	19
1.7 Bioarchaeology and the Study of Past Populations -----	20
1.8 Summary-----	21
CHAPTER 2: CULTURAL DEVELOPMENT IN PERU -----	23
2.1 Introduction-----	23
2.2 Spanish Contact in Peru-----	27
2.3 Spanish Contact in Lambayeque Valley -----	28
Figure 2. North coast population estimates, (Cook 1981). -----	29
2.4 Colonial Period Bioarchaeological Inquiry in the Lambayeque Valley -----	30
2.5 Summary-----	31
CHAPTER 3: ANDEAN GEOGRAPHY AND ECOLOGY: HUMANS AND THE ENVIRONMENT -----	32
3.1 Introduction-----	32
3.2 Andean Geography -----	32
Figure 3. Elevation map of Peru. (wikipedia.org, retrieved July 9, 2016).-----	33
Figure 4. The Humboldt Current. (wikipedia.org, retrieved July 9, 2016). -----	34
3.3 Cultural Ecology and Environmental Adaptations -----	36
3.4 Summary-----	37
CHAPTER 4: THEORETICAL AND METHODOLOGICAL FRAMEWORK -----	39
4.1 Introduction -----	39
4.2 Theoretical Approaches to Diet -----	41
4.3 Isotope Analysis-----	43
4.3.1 Chronological Applications of Teeth and Stable Isotope Analysis -----	44
4.3.2 Oxygen Isotope Analysis -----	44
4.3.3 Carbon and Nitrogen Isotopes -----	48

Figure 5. Protein regression and correlation with apatite $\delta^{13}\text{C}\%$ and collagen $\delta^{13}\text{C}\%$. Reprinted from Kellner and Schoeninger (2007).	48
4.4 Dental Microwear Analysis	51
4.4.1 Pits and Scratches	52
4.5 Conclusion	53
CHAPTER 5: STUDY DESIGN	54
5.1 Introduction	54
5.2 Study Population	54
5.3 Isotopic Methods	56
5.4 Dental Microwear Methods	57
5.5 Summary	57
CHAPTER 6: STATISTICAL ANALYSIS AND RESULTS	59
6.1 Introduction	59
Table 1: Total samples by age class and site.	60
6.2 Results of Dental Microwear Analysis	61
Table 2. CNS sample population sorted by sex.	61
Table 3. CNS sample population sorted by age class.	62
6.3 Cross-tabulation with Chi-Square Test of Significance	65
Table 4. Cross-tabulation with Chi-Square results.	65
6.4 T-Tests	67
Figure 6. First T-Test results.	67
Figure 7. Second T-Test results.	68
Figure 8. Third T-Test results.	69
6.5 Associations Between Microwear Results and Isotopic Data	70
Table 5. Summary of individual profiles. a Values are expressed permil (‰) relative to the Pee Dee Belemnite geological standard (vPDB).	71
Figure 9. Fine scratches and $\delta^{13}\text{C}$ deviate significantly from horizontal, indicating a strong positive relationship between the variables.	73
CHAPTER 7: CONCLUSIONS AND FUTURE RESEARCH	74
7.1 Findings	74
7.2 Future Research	75
7.3 Conclusions	75
BIBLIOGRAPHY	77

LIST OF TABLES

Table 1: Total samples by age class and site. -----	60
Table 2. CNS sample population sorted by sex. -----	61
Table 3. CNS sample population sorted by age class. -----	62
Table 4. Cross-tabulation with Chi-Square results. -----	65
Table 5. Summary of individual profiles. aValues are expressed permil (‰) relative to the PeeDee Belemite geological standard (vPDB). -----	71

LIST OF FIGURES

Figure 1. Archaeological sites and physical features of the Lambayeque Valley; Eten highlighted. (Klaus and Alvarez-Calderon, in press).	15
Figure 2. North coast population estimates, (Cook 1981).	29
Figure 3. Elevation map of Peru. (wikipedia.org, retrieved July 9, 2016).....	33
Figure 4. The Humboldt Current. (wikipedia.org, retrieved July 9, 2016).	34
Figure 5. Protein regression and correlation with apatite $\delta^{13}\text{C}\%$ and collagen $\delta^{13}\text{C}\%$. Reprinted from Kellner and Schoeninger (2007).	48
Figure 6. First T-Test results.	67
.....	
Figure 7. Second T-Test results.	68
Figure 8. Third T-Test results.	69
Figure 9. Fine scratches and $\delta^{13}\text{C}$ deviate significantly from horizontal, indicating a strong positive relationship between the variables.	73

CHAPTER 1: STUDY INTRODUCTION

1.1 Introduction

From the 15th to 18th centuries, a number of European nations embarked on extensive overseas exploration in an effort to extend their cultural, economic, and political influence. This "Age of Discovery" led to European encounters with many regions inhabited by non-Europeans and the later establishment of colonial empires. European colonies in Africa, Asia, and the Americas furthered the expansion of a global trade network and catalyzed European influence in territories previously occupied by indigenous populations. Rarely did European colonial expansion peacefully coexist with indigenous populations; rather, indigenous populations were often enslaved, exploited, or otherwise negatively impacted by colonization. Historical records of colonization are notoriously biased; often, indigenous populations had no written language. Further, the adage "history is written by the victors" certainly holds true in the early colonization of the Americas. As such, the contemporary understanding of European colonization of the New World is heavily based upon European records. Through archaeological inquiry, however, a more complete story of colonization can be told.

1.2 A Brief History of Eten

This study considers skeletal materials from the colonial-period sites of la Capilla de Santa Maria Magdalena de Eten (CSMME) and la Capilla de Nino Serratino (CNS) in northern coastal Peru. This site complex is located in the Lambayeque Valley, which contained roughly a third of the total population of the entire late pre-Hispanic Peruvian coast (Kosok 1965). Consisting of the Motupe, La Leche, Lambayeque, Reque, and Zaña rivers, the Lambayeque Valley was home to the greatest amount of arable land on the pre-Hispanic coast (Kosok 1965).

This arable land fostered the development of many pre-Hispanic cultures; key developments in the Cupisnique, Moche and Sicán cultures all occurred in the region (Shimada 1990, 2000).

Anthropological understandings of Colonial Lambayeque are poorly developed when compared to other colonial areas, limited by the understudied nature of post-Contact Peru and the lack of a Spanish chronicler in the Colonial Lambayeque Valley. Much of what is known to date is derived from careful consideration of existing historical documents, as well as archaeological inquiry and local oral histories, which are the primary source of info about colonial Eten (Ramirez 1996).

According to oral history and corroborated by correlating historical documents, Eten was founded in 1533 by a lone, venturesome Franciscan missionary. Contacting a Muchik community called Atim that was likely a specialized fishing village, the Franciscan constructed a mission church, and renamed Atim, Santa Maria Magdalena de Eten -- or simply, Eten (Salas 2004). By the late 16th century, Eten's population of nearly 1000 appears to have been one of the most demographically and economically stable communities in the Lambayeque Valley (Ramirez 1996). As Hispanic influence drove the community of Eten to outgrow the church erected one hundred years earlier, La Capilla de Santa Maria Magdalena de Eten (CSMME) was constructed sometime between approximately 1620 and 1640 to replace the original church. In 1649, church officials from the nearby city of Chiclayo confirmed mystical apparitions of the Christ Child at CSMME, cementing Eten's place as a pilgrimage site to this day (Klaus 2012). Local legend tells of a devastating hurricane that drove the population from Eten sometime near 1750, though no paleotempestology data exist to confirm this; more likely is that the population was driven to evacuate Eten by the unrelenting encroachment of sand dunes (Klaus and Alvarez-Calderon in press:10). Following 1750, the population of Eten appears to have separated and established two

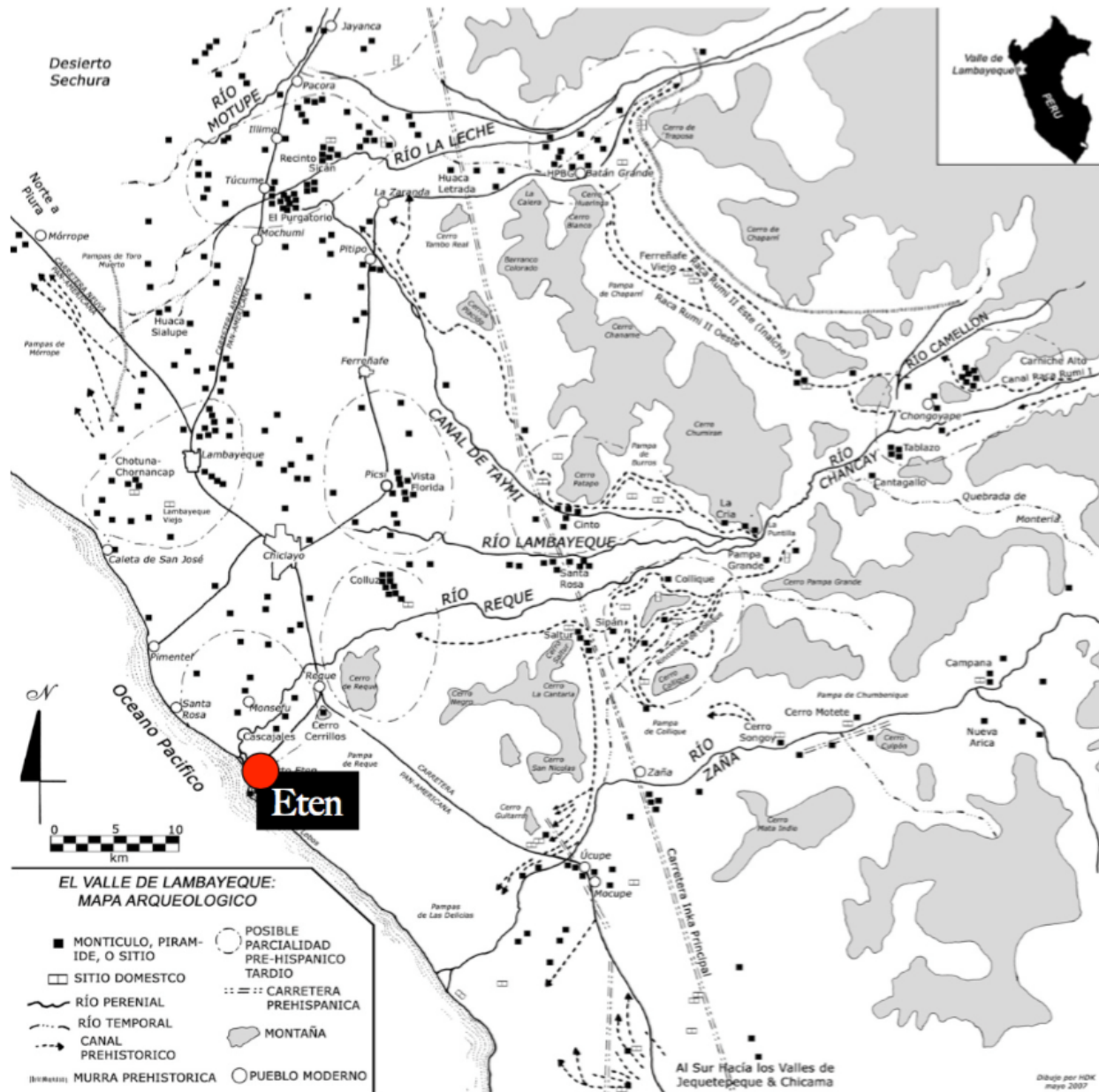


Figure 1. Archaeological sites and physical features of the Lambayeque Valley; Eten highlighted. (Klaus and Alvarez-Calderon, in press).

separate villages; fishers established Puerto Eten one kilometer to the south, while those with more terrestrial practices established Ciudad de Eten one and a half kilometers to the northeast. Interestingly, excavations at Eten revealed that many structures appear to have been moved brick-by-brick to their new locations (Klaus and Alvarez-Calderon, in press).

A few years after the population of Eten split into smaller settlements, the Christ Child appeared again, reportedly saving a failing vessel just off the beach of Eten. Miguel Castillo, the captain of the floundering vessel, built a new chapel, *La Capilla del Nino Serranito* (CNS), approximately 150 meters southwest of CSMME to commemorate the event. CNS (constructed approximately 1776 A.D.) was built atop the first mission church of Eten (built in 1533 A.D.). The burial population at the CNS site was interred during the operation of this earlier mission church. Therefore, the burial population at CNS dates to the Early- to Mid-Colonial Period (1533-1620). Archaeological inquiry at CNS suggests that the chapel was never active or consecrated; however, the chapel stood in commemoration of Castillo's rescue until after the turn of the 20th century, when it appears to have been abandoned.

1.3 Purpose of this Study

The purpose of this study is to help expand the story of Spanish contact in the Lambayeque Valley of northern Peru. By applying dental microwear and stable isotope analyses, this study seeks to better understand the diet of Muchik individuals interred at two sites in the coastal town of Eten in the Lambayeque Valley: La Capilla Santa Maria Magdalena de Eten (CSMME) and La Capilla Del Nino Serranito (CNS).

Excavations at CSMME conducted by Klaus (2012) led to the discovery of 253 burials representing the remains of at least 450 individuals. The majority of these burials date to the

Mid- to Late Colonial Period (A.D. 1625-1760). Excavations at CNS revealed 256 burials representing at least 308 individuals dating to the Early Colonial Period (A.D. 1533-1620) at the site of La Capilla del Nino Serrañito. From these burial populations, 18 individuals from CNS and 17 individuals from CSMME were selected for dental microwear analysis. Of the 35 individuals included in the study, age class data were available for 30 individuals and sex data available for 19. Also, stable isotope analysis was conducted on many of the CNS samples.

Bone and enamel carbonate were analyzed for $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$. Because enamel does not remodel, enamel carbonate isotope values are markers of an individual's early life (isotope values in teeth correspond to that tooth's formation). Unlike enamel, bone remodels throughout life. Therefore, bone isotopes are indicative of an individual's consumptions in the last 5-20 years of life (Knudson 2004). Finally, dental microwear analysis provides perspective on an individual's consumption patterns very late in life, though more destructive microwear can persist for years.

1.4 Expected Results

Drawing from recent research on the same population, I hypothesize that the Muchik individuals interred at these sites do not exhibit a significant shift in diet as a result of the significant transformations in the Lambayeque Valley from the Early- to Late-Colonial Periods. Klaus and Alvarez-Calderon (in press:16) describe the Muchik people of Eten as "enduring measurably less childhood and adult stress, higher birthrates and female fertility, and less arduous forms of physical activity" than individuals in neighboring Mórrope. I hypothesize that the individuals at Eten were relatively healthier than those at Mórrope partly because the population at Eten maintained a healthier, more varied diet.

Analysis of the dental microwear data will discover any differential access to food based on biological sex or age. A known relationship exists between food systems and social systems (e.g., Bourdieu 1979; Hastorf 1996). Particularly, food systems reflect gender relationships - “gender” in this context is inferred from the division of labor associated with food production (Hastorf 1996). Individual diet should, therefore, portray different social positions and functions in societies where such gaps exist. Given the flattening of Andean cultures under colonial Spanish rule (further discussed in Sections 2.1-2.3), I hypothesize that differential access to food is largely mitigated. Thus, I do not expect to find any significant microwear or isotopic differences between the biological sexes that would indicate gendered variation, especially in the later CNS population.

1.5 Contributions to Contemporary Understanding

A small collection of significant bioarchaeological projects forms the foundation for the contemporary understanding on indigenous diet and subsistence during Spanish colonization of the Americas. In particular, Larsen’s (2001) bioarchaeological work in the Southeast United States has significantly influenced contemporary understandings of European contact and its impacts on indigenous populations. To date, this ongoing research is the most influential bioarchaeological inquiry undertaken regarding Spanish contact in the Americas. Ubelaker’s (1994; with Ripley 1999; with Tam 2000; with Newson 2002) bioarchaeology research throughout the northern Andes is one of few projects of comparative scale to Larsen’s. Further, Ubelaker’s study is the only long-term regional survey to include Colonial period skeletons from the northern Andes (Ubelaker 1994; Ubelaker and Ripley 1999).

Bioarchaeological research is frequently conducted throughout the Andes due to the ideal conditions for preservation. However, very little research considering Colonial and post-Colonial populations has been conducted. Wernke (2011, 2013), Quilter (2007, 2011), Klaus (2008, 2012, in press; with Tam 2009) and Turner (2009) first applied historical bioarchaeology in the Peruvian Andes, and continue to be active figures in this area of study. Localized studies such as these provide valuable information concerning the lives of individuals from past populations, which can be used to advance broader understandings of Spanish contact throughout the Americas. My research will contribute another localized study to the cumulative groundwork currently being laid for a larger regional survey of the Colonial Period north coast. As more research contributes to the growing body of literature considering European colonization in northern Peru, a broader understanding of the region will be developed, and will inform studies of colonization across time and space.

1.6 Contact Period Peru: Balancing Historical and Archaeological Accounts

The Muchik, like other ancient Andean civilizations, left no discernible written narrative. Until recent anthropological efforts, only ethnohistorical accounts recorded by 16th century Spanish chroniclers were available to understand indigenous life in the ancient Andes (Von Hagen and Morris 1998:201). In the Central Andes, chronicles by Father Bernabé Cobo (1990 [1653]) and Pedro De Cieza de León (1999 [1537]) are the most complete accounts of Inca politics and ideology (Andrien 2001:5; Von Hagen and Morris 1998:201; Turner 2008:1). Other primary documents of the Spanish colonizers, such as administrative documents and census data, provide additional insight into the lives of people in Colonial Peru (Von Hagen and Morris 1998:201; Klaus 2008:282). Historical narratives often record only the ethnocentric perspective

of those who write them. Spanish chronicles, therefore, are widely considered to contain misrepresented portrayals of indigenous lifeways in pre-Hispanic and Colonial Peru (Ramirez 1996:1).

Anthropology is the counterweight to right the historical scales imbalanced by ethnocentric Spanish chronicles. Analyses of material and human remains have proven to be effective tools with which to learn more about colonized, and colonizing, populations (Deagan 2003; Larsen 2001; Ramirez 1996). In the Andes, archaeological inquiry has emphasized the systematic destruction of Andean lifeways by the transformations caused by Spanish colonization. Hundreds of indigenous communities in Colonial Peru were forcefully relocated into *reducciones* and forced into hard labor (Andrien 2001; Klaus 2008; Klaus and Tam 2009; Ramirez 1996). Across the Lambayeque Valley, thousands packed into massive *haciendas* and were forced to farm sugarcane and alfalfa or raise livestock (Klaus and Tam 2009:357). Previous investigations have shown that the forced resettlement of indigenous populations destroyed indigenous political, economic, and cultural systems, exacerbated the spread of disease, and significantly impacted the environment (Deagan 2003:5; Klaus 2008:325).

1.7 Bioarchaeology and the Study of Past Populations

Bioarchaeology is the discipline that provides the most direct evidence of studying diet, disease, and stress in past populations (Larsen 2002; Buikstra 1977). Skeletal remains contain many complementary indicators of diet and disease, which enable at least a partial reconstruction of individual life history. Together, multiple life histories in a population provide a means to broadly infer lifeways and adaptations of large social groups. (Simpson 1991:241).

Stable isotope analysis is among the most comprehensive methods through which to gain information regarding an individual's life history. By analyzing the chemical makeup of both soft and hard tissues, stable isotope analysis can reveal temporal and absolute data about an individual's diet, migration, lactation patterns, and exposure to pathogens - to name but a few applications (further discussed in Section 4.6).

Stable isotope analysis is widely used by bioarchaeologists because of the broad range of data that can be gleaned from a thorough study. Though a number of broad-spectrum stable isotope analyses have been conducted, researchers generally focus on only a handful of isotopes in a single analysis. By focusing on a subset of the available stable isotopes, researchers are able to profile a fragment of an individual's life history, and compare those data with other individuals in the studied population. Collectively, the data can then be extrapolated to better understand the studied population and inform further research questions.

Dental microwear provides additional information about diet that cannot be obtained using stable isotopes. For example, dental microwear is a record of mastication and tooth use and can distinguish between tough and brittle foods as well as hard-object consumption. Furthermore, dental microwear provides an independent method to verify inferences from stable isotopes concerning gender, age variation and site differentiation.

1.8 Summary

In the next Chapter, cultural development in Peru (particularly on the north coast and as it relates to the studied population) is briefly discussed. In Chapter 3, the geographic and environmental conditions in which these cultures lived are elucidated. After establishing the necessary historical background for this study, bioarchaeological theory of dietary reconstruction

is summarized and the methods for conducting stable isotopic analysis and dental microwear analysis are examined in Chapter 4. The design of this particular study is described in detail in Chapter 5, with results and the associated discussion presented in Chapter 6. Chapter 7 provides conclusions on this study and offers suggestions for future research.

CHAPTER 2: CULTURAL DEVELOPMENT IN PERU

2.1 *Introduction*

While human occupation of the Peruvian north coast dates to at least 8000 B.C. (Shimada 2008:61), permanent settlement did not emerge until 2500-2000 B.C. (notably at Huaca Prieta and Alto Salaverry) (Bird et al.1985; Moseley 1975, 1978). With agricultural lifeways firmly entrenched by 1800-1500 B.C., cultural developments swiftly occurred. Populations grew and became increasingly complex; pottery-making became an integral part of craft production and artistic expression (Shimada 2008:61). With these developments, distinguishable cultures began to emerge.

From 1500 to 600 B.C., the Cupisnique culture had considerable influence along the Peruvian north coast (Klaus and Toyne 2016; Elera 1998; Shimada 1994). During the Cupisnique influence, a contemporary population - the Chavín horizon - arose in the highlands around 900 B.C. Though the relationship between these cultures is not fully understood (Shimada 2008:62; Burger 2008), Shimada (2008:62) argues that recent investigations confirm "Cupisnique's autogenous origin and temporal priority over the Chavín." Further, the "formalization of the Chavín style....was closely linked to input from the Cupisnique style centered on the north coast" (Shimada 2008:62). Burger (2008), however, maintains that while the Chavín horizon was a highland polity, they were known to have had coastal influence. The Cupisnique influence declined around 600 B.C.; while this decline is poorly understood, Elera (1998) speculates that a major El Niño event may have destabilized the population.

Before the rise of the next prominent coastal culture, a series of less-influential pottery styles rose and fell. Shortly after the decline of the Cupisnique, the Salinar style emerged on the

north coast. Though poorly understood, the Salinar may represent an expansion of highland influence (likely stemming from the Chavín) to take advantage of the collapsed Cupisnique culture (Klaus and Toyne 2016; Burger 2008). Around 200 B.C., the Gallinazo culture replaced the declining Salina style and formed the “roots of a north coast biological and coastal substratum that continued to exist...under the surface of later north coast societies” (Klaus and Toyne 2016; Klaus 2014; Shimada and Maguina 1994). The Gallinazo culture persisted until the rise of the Moche around 100 A.D.; some Gallinazo polities likely assimilated into the proliferating Moche culture, while others appear to have retained their cultural identity and co-existed with the Moche (Bourget 2003).

Coalescing from disparate polities along the north coast around 100 A.D. likely as a result of shifts within the Gallinazo sociopolitical system, the Moche grew to become the one of the most significant pre-Inca developments on the Peruvian north coast (Klaus and Toyne 2016). The Early Moche Period (100 A.D.-300 A.D.) is characterized by the emergence of the Moche on the north coast. Two polities formed during the emergence of the Moche - a northern polity centered on Sipan in the Lambayeque Valley and a southern polity centered on Huacas de Moche in the Moche-Chicama region (Castillo and Donnan 1994; Shimada 1994). Throughout the Early Moche Period, the northern polity exercised a prevailing influence over the southern polity.

The Middle Moche Period (300-550 A.D.) is characterized by a shift of power from the northern to southern Moche polity (Klaus and Toyne 2016). The more powerful southern Moche grew quickly, annexing the northern Moche and expanding southward to the Huarmey Valley (Shimada 1999). As the southern Moche grew more powerful, Huacas de Moche became more developed. Specifically, an urban core with residences and workshops emerged, bookended by

two temples - the Huaca del Sol and Huaca de la Luna (Klaus and Toyne 2016; Chapdelaine 2001). Between 450-550 A.D., the southern Moche influenced over 350 kilometers of the Peruvian north coast. The political structure of this most influential Moche realm is debated; Billman (2002) contends that this was the first state of the region, while Shimada (1999) postulates that the realm is better understood as confederation of associated - yet competitive - chiefdoms.

No matter the prevailing political structure, destructive climatic events caused significant social and political change around 550 A.D. - marking the end of the Middle Moche Period and the influence of southern Moche ideology (Shimada et al. 1991). These polarized climatic events disrupted the Moche way of life and shook the popular faith in the gods - faith that was based in part on the gods providing stable, beneficial weather.

In place of the fallen southern Moche systems, southern Moche elites relocated to the middle Moche valley and attempted to regain power by distancing themselves from the upended religious system (Bawden 2005). Around the same time, the northern Moche reorganized, marking the beginning of the Late Moche Period (550-800 A.D.) (Shimada 1994). This reorganization resulted in the final consolidation of Moche power into a state-level political system - this time centered at Pampa Grande in the Lambayeque Valley (Shimada 1994). Around 750 A.D., the Moche's political power disintegrated for good, giving rise to a destabilized period that lasted until the Sicán Culture rose to prominence by 900 A.D. (Shimada 1994).

The Early Sicán Period (800-900 A.D.) is characterized by a rise to prominence; not until the Middle Sicán Period (900-1100 A.D.) did the culture exert regional influence. Centered on the religious complex of Sicán in the La Leche Valley, the Sicán culture shifted power on the

north coast back to the northern reaches, spanning from present-day Ecuador to the Chicama Valley (Shimada 1990, 2000, 2014). During the Middle Sicán Period, the Sicán established a strong trade network based on agriculture, marine resources, and bronze (Shimada 1982), and used that network to establish bonds with other political leaders throughout the north coast (Shimada 2014). Though the Sicán cultural system was pervasive, the people of the Sicán - particularly the non-elites - appear to have retained Moche/Muchik cultural identities as well (Klaus 2014).

Around 1100 A.D., another particularly strong El Niño brought floods and drought, destabilizing the region once more (and marking the start of the Late Sicán Period). As the political and religious order of Sicán broke down, temples atop the huacas at Sicán were purposefully burned (Shimada 2000). In an effort to reestablish political order, the capital was moved to Túcume in the early 12th century, where the Sicán exerted limited influence over the north coast until conquest by the Chimú in 1375.

Arising in the Moche Valley south of Sicán influence, the destabilization of the Sicán around 1100 A.D. allowed the Chimú culture to gain prominence and return the prevailing influence to the southern north coast (Kolata 1990; Klaus and Toyne 2016). During the 12th century, the Chimú consolidated their influence throughout the Moche Valley and the immediate surrounding area (Klaus and Toyne 2016). This period also saw the development of the Chimú capital of Chan Chan, which would grow to be the largest known pre-Hispanic city in South America (Klaus and Toyne 2016). Solidified in the Moche Valley, the Chimú began to expand their influence around 1200 A.D.; by 1375 A.D., the Chimú exerted influence from the southern border of present-day Ecuador south to the Peruvian capital of Lima (Mackey and Klymyshyn

1990). The Chimu reached the height of their influence contemporaneously with the Inca rise to power, and resisted assimilation into the Inca Empire. Around 1470 A.D., the Inca conquered the Chimu (Klaus and Toyne 2016), paving the way for the largest imperial state in the Americas prior to Spanish contact.

The Inca Empire rose from present-day Cusco in the early 13th-century (Covey 2003). The Inca rapidly expanded their power, first throughout the Cusco Basin, then with allies to the north and west. While the empire increased quickly in population, power, and scope, the implementation of the *mit'a* system exponentially accelerated the empire's influence. Simply, the *mit'a* system was a form of taxation that required the payment of tribute to the state, which filled the empire's coffers as a result of expanding state influence. Further, the Inca adopted pre-existing monuments and ideas, incorporating them into larger expansionist plans. The unification of these existing social systems spurred the Inca Empire to flourish on an unprecedented scale. In less than a century, the Inca Empire stretched 4000 kilometers from north to south. By the early 15th century, the Inca ruled a vast empire and controlled a wide variety of resources. The large population provided for a strong military and efficient administrative structure, which in turn furthered the rapid territorial expansion of the empire (Von Hagen and Morris 1998; Covey 2003).

2.2 *Spanish Contact in Peru*

In the mid-15th century, the Inca met a new empire - one even larger and more powerful than their own. Contact between the Inca and their Spanish counterparts was violent and devastating to indigenous lifeways. Soon, the Spanish Empire of the 16th century would replace the Inca Empire as the most influential in South America.

Throughout the Americas, Spanish institutions reshaped the lives of indigenous populations. Broadly, Spain sought to colonize the Americas to: (1) spread the power of the Spanish Empire; (2) spread Catholicism throughout the known world; and (3) exploit any resources possible to the Crown's greatest benefit. In the process, networks of indigenous villages were condensed to more efficient (and therefore more productive) *reducciones*.

The consolidation of indigenous populations into *reducciones* was perhaps the most devastating of Spanish colonial practices. Spanish colonists were able to exploit the labor force more readily, while indigenous populations lived in drastically overpopulated and severely unsanitary conditions (Klaus 2008:286). The relocation of Native Americans to *reducciones* destroyed indigenous social and cultural systems and provided ground zero for the spread of myriad diseases throughout indigenous and Spanish populations (Klaus 2008:286).

2.3 *Spanish Contact in Lambayeque Valley*

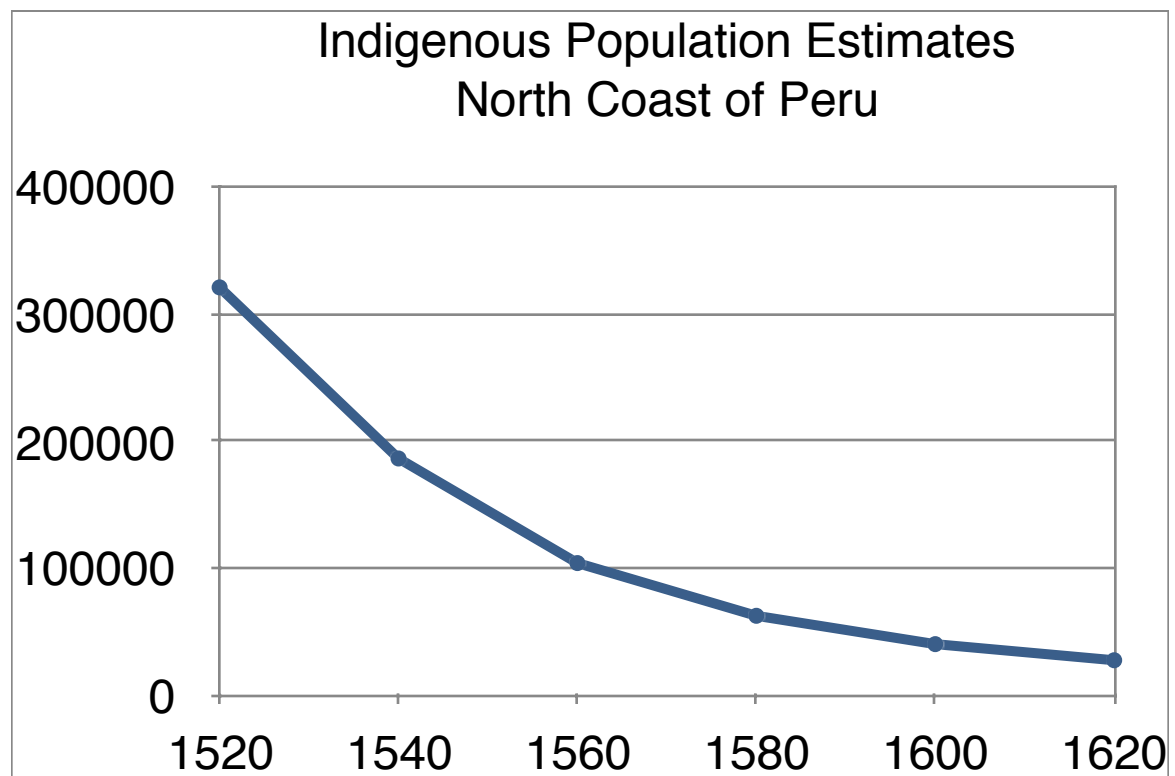
On November 16, 1532, the Inca and Spaniards fought at Cajamarca in a battle that cannot be overstated in importance (Klaus 2008:282). The Inca were defeated at Cajamarca, and by November 1533 the Inca capital of Cusco had fallen to the Spaniards - for all intents and purposes marking the end of the Inca Empire (Klaus 2008:282).

Spanish impact on the north coast followed soon after conquest of the Inca at Cusco. While Pizarro passed through the Lambayeque Valley in October 1532 (Mendoza 1978:178-179), an administrative center for the north coast (at Trujillo) was not established until 1534 (Klaus 2008:305). Also in 1534, Pizarro issued the first *encomiendas*, politically dividing the Lambayeque Valley (Klaus 2008:305).

At the same time Pizarro was reorganizing the newly conquered Inca Empire into an administrable political system, the Lambayeque Valley experienced significant depopulation as a result of both in-fighting and the diseases brought by Spanish contact (Klaus 2008:307; Cook 1981). Klaus (2008:307) describes the forced high population densities in coastal river valleys as “ideal disease reactors...which provided ideal conditions for maximum mortality from introduced pathogens” (citing Cook 1981:143).

Figure 2. North coast population estimates, (Cook 1981).

The forced resettlement of Pre-Hispanic Muchik populations into *reducciones* permitted



the Spanish great control over the indigenous people. Informally instituted in the Lambayeque Valley as early as 1534 (Mendoza 1985), *reducciones* were a biologically and culturally destructive environment. To compound matters, many *reducciones* were placed in areas known by natives to pose significant environmental dangers - for instance, the Spanish founded many

early *reducciones* and towns within the flood plain, a number of which were destroyed by the 1578 El Nino floods (Klaus 2008:321).

2.4 *Colonial Period Bioarchaeological Inquiry in the Lambayeque Valley*

Klaus (2008, 2012) conducted the first bioarchaeological study of the post-contact Peruvian north coast with his excavation of La Capilla de San Pedro de Morrope in the northwest corner of the Lambayeque Valley. In later studies, Klaus excavated at nearby Eten to test a number of hypotheses about regional patterns of contact in the Lambayeque Valley. The burial population at Eten did not exhibit many of the characteristics common amongst contemporary indigenous populations attributed to Spanish contact - including those at Morrope. While Spanish influence at Eten was likely similar to that at Morrope, the burial population at Eten was skeletally healthier (Klaus 2012). Individuals interred at Eten lived less stressful lives, had higher fertility rates, and experienced less arduous physical activity (Klaus 2012). Klaus (2012) theorizes that this difference is caused by the more favorable environment at Eten. Eten lies in a fertile ecosystem where the Reque River meets the Pacific Ocean in the southwest corner of the Lambayeque Valley. The fertile region surrounding Eten provided for a variety of readily-available foods, even after conquest. Paleoethnobotanical investigations at Eten indicated the consumption of many fruits and vegetables, including maize, beans, peppers, oranges, bananas, gourds, tomatoes, and potatoes. Faunal remains at Eten provided evidence of the consumption of substantive marine resources and terrestrial animals such as sheep, goats, cows, pigs, ducks, and rabbits (Del Alcazar 2011; Puse 2012). The Muchik population likely continued fishing even after Spanish contact. Furthering this assertion is a higher frequency of rib fractures in the burial population at Eten. Muchik fishermen maintained a long seafaring tradition of venturing into

hazardous waters in small boats. Fishermen were easily tossed about in their boats by heavy surf and a rocky coastline; the constant jostling in their boats likely led to traumatic fractures in their chest and midsection (Klaus and Rosabella, in press).

2.5 *Summary*

Though Spanish contact had severe repercussions throughout the Peruvian north coast, populations were differentially impacted post-Contact. Even near-neighboring populations (such as those at Morrope and Eten) appear to have had vastly different colonial experiences. Klaus (2012) theorized that the environmental conditions at Eten were much more favorable to maintaining population health, and therefore led to the discovery of a skeletally healthier burial population at Eten. The larger geographic and climatic systems in which these favorable (and unfavorable) environmental conditions exist will be further discussed in Chapter 3.

CHAPTER 3: ANDEAN GEOGRAPHY AND ECOLOGY: HUMANS AND THE ENVIRONMENT

3.1 *Introduction*

As evidenced in the previous chapter, the diverse Peruvian landscape and tempestuous climate played a significant role in shaping the social and economic systems of Pre-Hispanic cultures. (Moseley 1992; Turner 2008). Despite the obstacles posed by their natural environment, many north coast cultures thrived because of their efficient exploitation of resources, development of trade networks, and technological developments to overcome natural challenges (Von Hagen and Morris 1998:14). This chapter describes the general geography of the region and the relevant dynamics of the Pacific Ocean before briefly discussing cultural adaptations to the Peruvian north coast.

3.2 *Andean Geography*

The Andes are divided into three regions (Northern, Central, and Southern) that span 7000 miles from Venezuela to Argentina. Within the Central region, three separate geographic zones exist: the coast, highlands, and tropical forests (Von Hagen and Morris 1998:14). The Central Andes are characterized by diverse, vertically stratified ecological zones that are densely populated and heavily cultivated (Klaus 2008:72; Turner 2008). Particularly, the environments of northern Peru are significantly shaped by the Humboldt Current and the South American Cordillera (Moseley 1992:25).

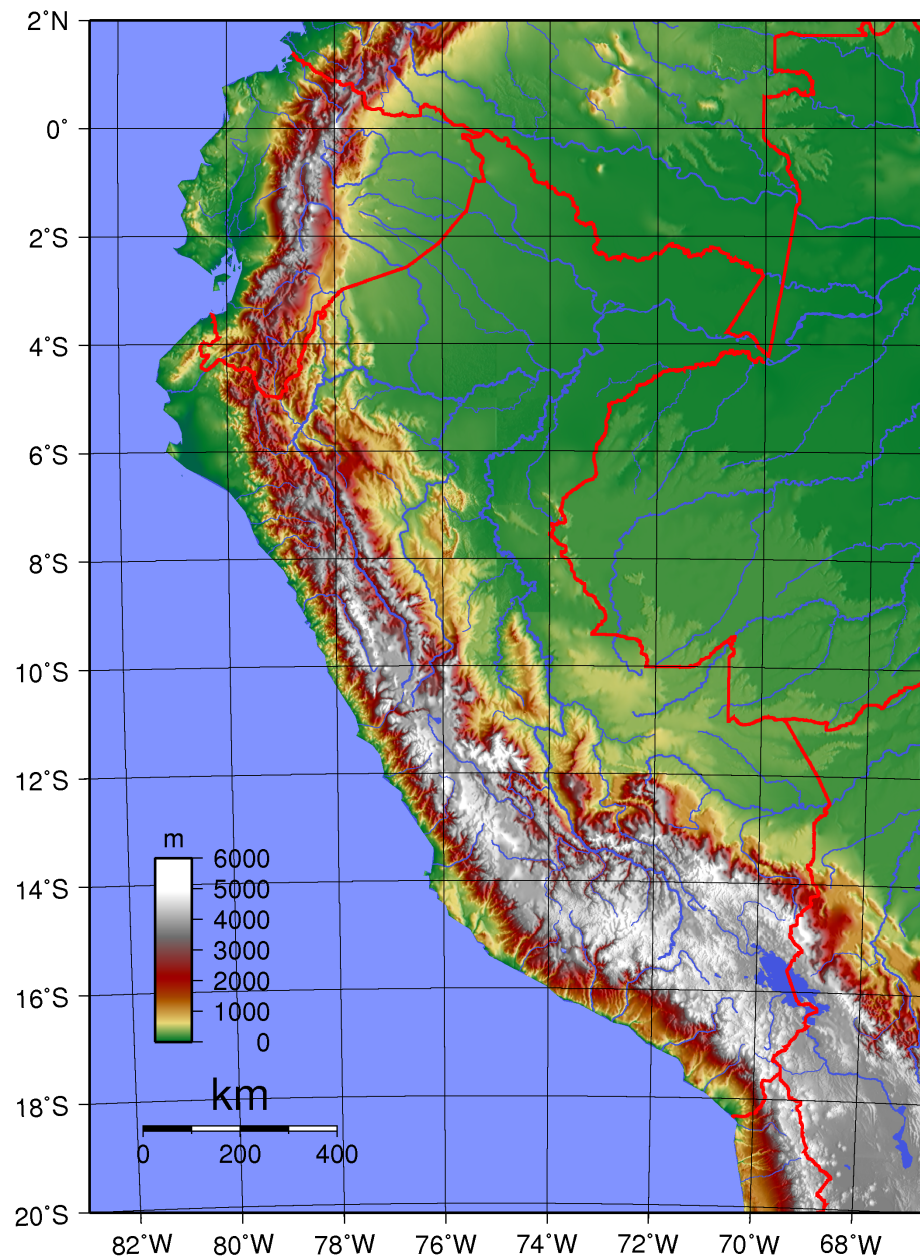


Figure 3. Elevation map of Peru. (wikipedia.org, retrieved July 9, 2016).

The Humboldt Current is largely responsible for the extreme aridity of Peru's coastal plains (Von Hagen and Morris 1998:14). The Humboldt Current moves northward along the western coast of South America, carrying cool water from near Antarctica. The cold current cools the prevailing onshore winds, which are then warmed as they pass over the coastal plains. This warming prevents the air from condensing as rain along the coast (Von Hagen and Morris

1998:14-15; Keatinge 1988:43). The air is cooled again upon reaching the Andean highlands, where heavy clouds are formed. The collision of cooled, then warmed, ocean breezes and the towering Andes results in a narrow strip of desert running the entire 2400 kilometers of the Peruvian coast, traversed only by 14 rivers - a number of them seasonal - streaming down from the highlands (Von Hagen and Morris 1998:14; Klaus 2008:78; Moseley 1992:42).

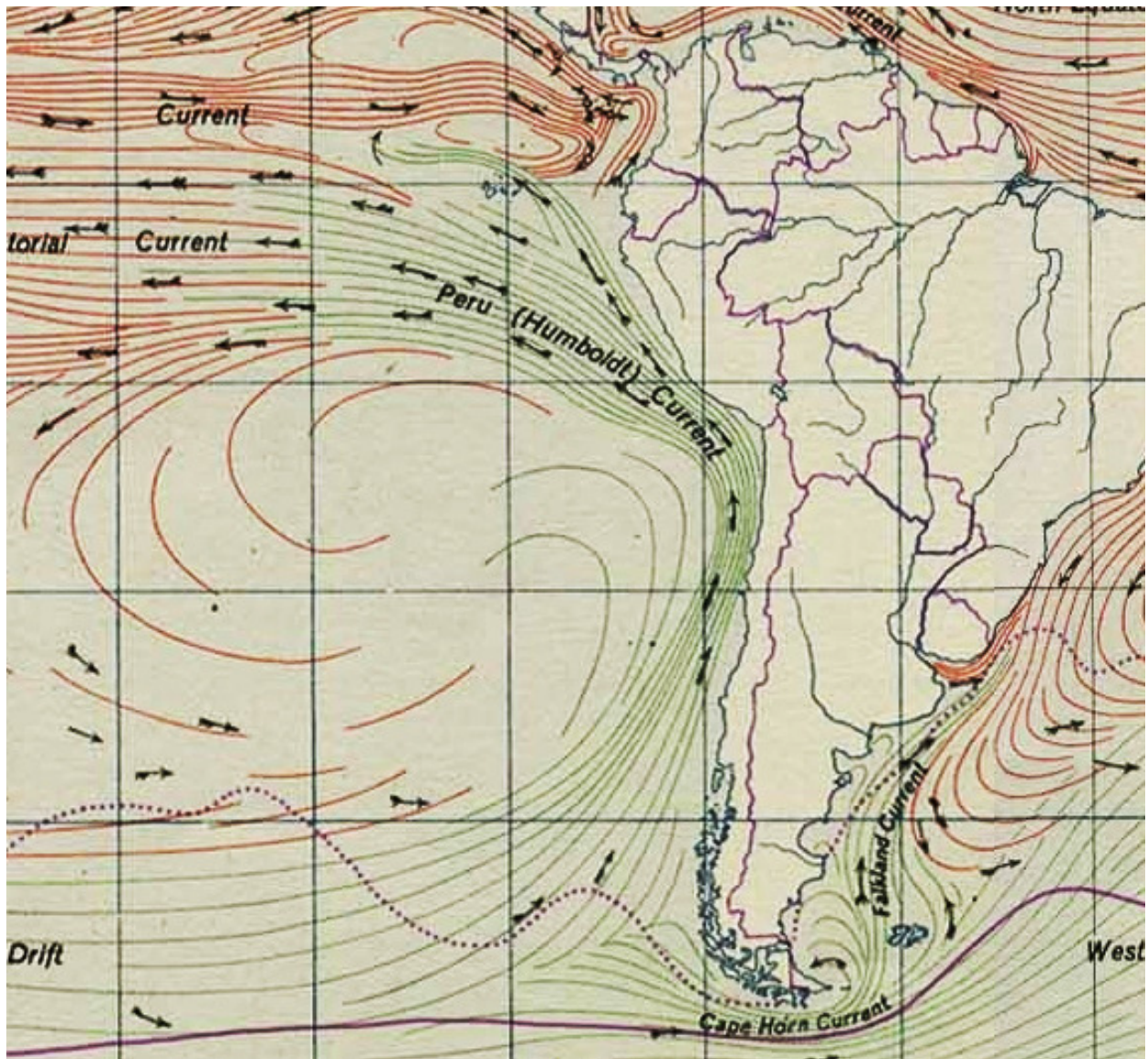


Figure 4. The Humboldt Current. (wikipedia.org, retrieved July 9, 2016).

The cold offshore current also creates a bountiful marine ecosystem. A phenomenon known as the “Ekman Spiral” forces nutrients to remain below the surface, which increases phytoplankton and leads to unparalleled biodiversity off the west coast of South America (Klaus 2008:79; Keatinge 1988:43). Access to these rich waters was fundamental to the development of complex Andean cultures, many of whom harvested marine plants and animals with regularity (Klaus 2008:79-80).

The South American Cordillera also plays an integral role in the environment of the region. The Cordillera is divided into three main zones: the *yunga*, the *quechua*, and the *puna*. The temperate western foothills, or *yunga*, lie to the east of Peru’s coastal desert. The warm, sunny *yunga* extend up to 2500 meters above sea level (masl), and are ideal for growing chili peppers, maize, and coca. The *yunga* are also rich in minerals such as copper, iron, and silver (Von Hagen and Morris 1998:14; Klaus 2008:77). Rainfall in the *yunga* provides water for the arid coastal valleys through rivers and underground aquifers (Klaus 2008:77). Beyond the foothills, fertile inter-mountain valleys in the *quechua* zone were extensively terraced by the Inca and used to grow maize, legumes, and grains such as *kiwicha* and *quinoa* (Von Hagen and Morris 1998:14). The *altiplano* region, or *puna*, begins 4000 masl, and is home to camelids such as llamas and alpacas. Historic and contemporary populations use these camelids for meat and weaving fibers (Von Hagen and Morris 1998:17-18).

On the eastern side of the *altiplano* begins the humid tropical rainforests. From the rainforest, indigenous populations collected for coca leaves, honey, medicinal plants, manioc, peanuts, sweet potatoes, and wood (Von Hagen and Morris 1998:18). Though contact between

eastern and western populations was severely limited by the high Andean peaks, cultures in the western foothills established an effective trade network with coastal populations.

Other climatic and geological phenomena also affected indigenous life in the Central Andes. The highly volatile Nazca Plate lies below Peru, which occasionally causes destructive earthquakes and volcanic eruptions (Von Hagen and Morris 1998:18; Klaus 2008:84). While not cataclysmic, El Niño is perhaps even more damaging than its geological counterparts (Von Hagen and Morris 1998:18). Occurring irregularly every few years, El Niño events alter the Humboldt Current, disrupting the fertile marine ecosystem off the Peruvian coast. This alteration causes severe droughts in southern Peru while flooding the north coast (Von Hagen and Morris 1998:22).

3.3 Cultural Ecology and Environmental Adaptations

Though the Central Andean environment is harsh, it held sufficient resources to support large, complex cultures (Klaus 2008:81). Indigenous Andean populations developed many complex solutions to overcome the physical challenges posed by the climate and geography of Peru. To combat the lack of water and little available arable land in the Andes, indigenous populations independently developed extensive irrigation systems. These systems linked multiple river valleys on the north coast, channeling water from perennial rivers to drier valleys (Von Hagen and Morris 1998:22). These complex irrigation systems transformed arid deserts into viable agricultural lands.

Further, Andean populations introduced terracing to overcome the challenge of farming on steep slopes (Moseley 1992:31). While the slope and rugged terrain becomes increasingly difficult at higher elevation, these heights experience a significant amount of precipitation even

during droughts (Moseley 1992:31). Terraces increased the amount of horizontal space, thus increasing the amount of arable land and providing for the cultivation of crops in previously-untenable lands (Von Hagen and Morris 1998:22).

Andean scholars describe the use of resources on two planes: vertical and horizontal. The “vertical archipelago” model suggest that indigenous populations utilized the various ecological zones on Andean mountainsides at the most opportune times for optimal resource production (Murra 1980). This model mitigated the challenges of seasonality and trading - most resources were attainable simply by ascending or descending the mountainsides. Further, this model enabled the harvesting of different crops at various times of the year, ensuring a consistent and stable food supply. Central to the “vertical archipelago” economic model was the *ayllu* system. An *ayllu*, or egalitarian local government, would establish outposts in different ecological zones to gather a broad range of resources, which were then redistributed throughout the region.

While the vertical model is widely applied to mountainous populations, a more horizontal mode is applied to coastal populations (Shimada 1982; Rostrorowski de Diez Canseco 1999; Moseley 1992). Coastal populations subsisted through the exploitation of abundant marine and terrestrial resources found along the Peruvian coast. Coastal communities rarely exploited highland resources directly; rather, coastal groups specialized in a few resources and relied upon trading with other communities to satisfy their resource needs (Klaus 2008:83).

3.4 *Summary*

Cultural development is heavily influenced by the environment in which the development takes place. On the Peruvian north coast, populations rose and fell by the effects of El Niño - not only did the pattern of flooding and drought cause substantial harm to populations’ ways of life,

it also shook their faith in the gods and destabilized entire social and political systems. Despite the damaging effects of El Niño, populations thrived on the north coast by adapting to their environment. Significantly, these cultures exploited the abundant marine resources enabled by the Humboldt Current and Ekman Spiral and created irrigation systems to harness water for irrigation in the river valleys. These adaptations enabled complex cultures to develop and flourish along the north coast of Peru for thousands of years.

CHAPTER 4: THEORETICAL AND METHODOLOGICAL FRAMEWORK

4.1 Introduction

The need to acquire or produce food has significantly influenced the development of all human societies. Even today, the quest for sustenance shapes health, social organization, group size, gender disparities, residence patterns, technology, and transportation. Further, societies are often categorized by their primary method of food attainment; humans hunt, gather, herd and farm to obtain sustenance and understanding subsistence practices can provide insights into larger cultural processes (Ambrose and Krigbaum 2003; Laffoon 2012; Price and Burton 2011).

The reconstruction of dietary life histories is a principal interest of bioarchaeological analysis. Many avenues for inquiry exist to understand the diet of individuals; through a combination of the methods that will be discussed, a more complete picture can be painted of an individual's diet through their life. Beyond elucidating an individual's general diet, dietary reconstruction can also answer questions regarding evolutionary history, growth and development, status, migration, and access to resources (Ambrose and Krigbaum 2003:193; Laffoon 2012; Price and Burton 2011).

Dietary life histories can be reconstructed through a number of methods. Dental pathologies are the most easily observed; caries and abscesses provide evidence for prolonged periods of malnutrition, poor hygiene, and major dietary shifts (Goodman et al. 1984). Micro- and macrowear patterns provide a look at the individual's dietary practice just prior to death. Biochemical analysis of bone carbonate, bone collagen, and enamel carbonate, among other archaeological tissues, characterizes aspects of the chemical makeup of an individual's bones that are influenced by their dietary practice (Ambrose and Krigbaum 2003). Further, floral and

faunal remains, middens, and other archaeological materials also contribute contextual information to dietary reconstructions (Ambrose and Krigbaum 2003; Laffoon 2012).

When reconstructing dietary patterns, multiple lines of evidence should be used to create the most comprehensive interpretation of diet. Williams and Holmes (2011), for example, describe how the diet of *Australopithecus africanus* appears distinct based on the prevalence of heavy microwear features. The large molars with broad occlusal surfaces in *A. africanus* have been linked to hard-object feeding, while SEM studies show pitting, and dental microwear textual analysis shows an even more intricate enamel surface potentially created from hard object foods and C₃ vegetation (Williams and Holmes 2011). Isotopic studies have revealed that *A. africanus* consumed C₄ plants or grazing animals that consumed C₄ plants (Williams and Holmes 2011). One explanation that accounts for the isotopic and microwear data difference is the C₄ chemical signature may be from underground storage organs, which could leave larger microwear features due to grit from the ground (Williams and Holmes 2011).

Similarly, Salazar-Garcia et al. (2016) analyzed human remains at Tossal de la Basses (Alicante, Spain) from three periods (Middle Neolithic, Late Roman, and Medieval) for dental microwear and carbon and nitrogen stable isotope ratios of bone collagen. Isotopic data revealed that diet for all periods was predicated on C₃ terrestrial resources, though marine protein was discernible during the Neolithic period and possible in some Medieval individuals. Microwear features on Neolithic and Medieval teeth reflected a diet predicated on tough foods, while Roman period teeth exhibited microwear traits associated with the consumption of softer, more prepared foods. Taken together, the microwear and $\delta^{15}\text{N}$ data suggest Neolithic and Medieval diets at Tossal de la Basses were predicated on grittier C₃ resources than Roman diets taken from

the same ecosystem, and that Neolithic and Medieval populations consumed more marine resources than their Roman counterparts. Both Williams and Holmes (2011) and Salazar-Garcia et al. (2016) stress the importance of combining analytical methods to create a synthetic reconstruction of ancient diet.

Dietary life history is invaluable in seeking to better understand the lives of past populations. By determining an individual's diet, the social and environmental factors acting upon individual throughout that individual's life become clearer. With multiple studied individuals in a population, this information becomes useful to answer questions of resource efficiency, migration, regional power, class, and status. Further, the reconstruction of dietary life history (and in a larger sense, bioarchaeological data in general) can be compared with historical documents when the latter are available to better understand the events that occurred and their ramifications on all involved. Many of these disparities are not fully recorded in written or oral history; it is only through bioarchaeological analysis that these differences can be more fully appreciated.

4.2 Theoretical Approaches to Diet

The processual school of archaeological thought framed early investigations of diet in an ecological perspective (Goodman 1998:152). As diet became a more commonly investigated subject, the early ecological framing led to the emergence of biocultural understandings of diet. (e.g., Harris and Ross 1987; Katz 1982; Katz et al. 1974; Ross 1978). Ross (1978) was one of the first to step away from a symbolic approach to diet and instead consider diet from a biocultural, or adaptational, perspective (Harris and Ross 1987:8). Similarly, scholars such as Winterhalder and Smith (1981) began applying theories of animal ecology - namely, optimal foraging theory -

to hunter/gatherer populations (Harris and Ross 1987:8). These developments anchored theoretical perspectives on diet from a distinctly biocultural perspective.

Cohen and Armelagos (1984) advanced this biocultural perspective by proposing the first comparative model based on bioarchaeological methods and data to measure biocultural stress across populations. However, this model primarily considered environmental factors (such the availability of food and water, climatic conditions) that impact disease and stress (Goodman 1984). A model predicated only on environmental pressures, however, overlooks the mitigating effects of cultural systems against these stressors. If these environmental pressures are insufficiently mitigated, they can reduce work capacity, mobility, and fertility throughout a population, which in turn can destabilize social, political, and economic systems (Klaus 2008:43).

Contemporary theoretical inquiry recognizes that, while cultural systems can counter the negative effects of environmental pressures, cultural systems can also have a destabilizing effect of their own. Cultural systems can bring about their own stressors, such as malnutrition and disease due to changes in subsistence strategies, social inequality, poverty, violence, and environmental degradation (Klaus 2008:43). Later iterations of the aforementioned biocultural model evolved to better encompass the effects of cultural systems - both positive and negative (Goodman 1998:152). Thus, the consideration of social, political, and economic perspectives is integral to understanding inequalities in access to and control of resources (Goodman 1998:152; Goodman and Leatherman 1998).

The consideration of diet from a biocultural perspective meshes with the acknowledgement that the human skeleton is both a biological and cultural entity (Agarwal and

Glencross 2011:1). In life, the body is readily understood as a physical manifestation of cultural expression. Similarly, the skeleton can be understood as a material representation of the social and political systems in which it existed (Klaus 2008:45).

4.3 *Isotope Analysis*

The food and drink we consume provide the nutrients needed to develop and maintain the human body. The elements and molecules in what is consumed contributes to the composition of bones and enamel. Traces of these elements and their isotopes can provide substantial information about individual diet.

Research in archaeological chemistry has primarily focused on carbon and nitrogen isotopes in human bone and enamel, though other isotopes are increasingly studied (Ambrose and Krigbaum 2003; Price and Burton 2011). Isotopes enter the body through the diet and are metabolized throughout the body, including the hydroxyapatite in bones and teeth. Stable isotope analysis relies on determining the ratio between two or more stable isotopes, which standardizes the measurement regardless of the absolute elemental concentration or material analyzed (Ambrose and Krigbaum 2003; Price and Burton 2011).

Hydroxyapatite is the substance of bone mineral and tooth enamel (Price and Burton 2011). Commonly known as apatite, it is comprised of carbonate and phosphate. This combination is complementary. Phosphate forms very strong bonds which are difficult to isolate for isotopic analysis, but very resilient to diagenesis. Alternatively, carbonate forms relatively weak bonds, making it much easier to isolate, but more susceptible to post-depositional breakdown. Collagen is the protein component of bone and tooth dentin, and is made of many

different components. A detailed analysis of isotopic values in these tissue substrates can provide insight into the type of protein consumed (Price and Burton 2011).

4.3.1 Chronological Applications of Teeth and Stable Isotope Analysis

Various tissue components represent different time periods in the construction of bone (Ambrose and Krigbaum 2003; Knudson et al. 2004; Laffoon 2012; Price and Burton 2011).

Collectively, studying these components enables the formation of a dietary life history. As bone apatite and bone collagen are constantly resorbed and replenished, their isotopic composition reflects dietary averages over at least the last ten or more years of an individual's life (Ambrose and Krigbaum 2003). The average rate of mature adult bone regeneration is 7-11 years, though ranges from 2 to 20 years have been observed (Knudson et al. 2004). The composition of tooth enamel, however, reflects diet during the age of crown formation, as it is not penetrated by any organic structures (Ambrose and Krigbaum 2003; Knudson et al. 2004).

Teeth provide multiple windows into an individual's life. Information about different stages of life can be gained by examining various dental characteristics. As specific tooth formation occurs at various times over the course of an individual's life, multiple tooth types can be analyzed to acquire isotopic information. (Wright and Schwarcz 1998). Isotopic values from the adult first and second incisors and first molar are representative of infancy or early childhood. The adult canines, second premolars, and second molar represent middle childhood, while the third molar represents adolescence (Hillson 1996).

4.3.2 Oxygen Isotope Analysis

Oxygen isotope values relate directly to the climate, temperature, and humidity of a locale (Tykot 2006). In bioarchaeology, this direct relationship can be utilized to study human

mobility (Price and Burton 2011:91). Oxygen isotopes in humans are established primarily through water consumption -- more specifically, through the consumption of rainwater or geological water (such as those from springs)(Ambrose and Krigbaum 2003; Knudson et al. 2004; Price and Burton 2011:92). Before considering the application of oxygen isotopes in the analysis of human mobility, it is necessary to first understand the utility of studying oxygen isotopes more generally.

Oxygen isotope values are reported as a ratio of ^{18}O to ^{16}O (Price and Burton 2011:91). This ratio is represented by $\delta^{18}\text{O}$ in parts per thousand (abbreviated as per mil or ‰) relative to the environmental standard of mean ocean water, or SMOW (Price and Burton 2011:92). Because the ratio of ^{18}O to ^{16}O depends on temperature-related processes such as evaporation, condensation, and transpiration, oxygen isotopes can be used as a proxy for atmospheric temperature.

Simply, the ratio of ^{18}O to ^{16}O is established through the operation of the familiar water cycle. When water evaporates from the ocean surface, the isotopically lighter ^{16}O isotope is released into the atmosphere first (Price and Burton 2011:91). This evaporation process forms clouds, which move inland and preferentially release the heavier ^{18}O isotope during precipitation (Price and Burton 2011:91). As rain clouds move further inland, they become progressively depleted of ^{18}O (Price and Burton 2011:91). Tropical, coastal, and summer precipitation is heavier than polar, inland, and winter precipitation (Price and Burton 2011:91). As in ocean water, inland water also preferentially evaporates ^{16}O , thereby concentrating the heavier ^{18}O isotope in inland surface water (Price and Burton 2011:92). In addition, plants preferentially release the lighter ^{16}O during evapotranspiration and retain the heavier ^{18}O (Price and Burton

2011:92). Intuitively, these $\delta^{18}\text{O}$ differences are magnified in arid regions, where evaporation occurs more readily than in humid climates. Finally, ^{18}O is further depleted by condensation at higher elevations and latitudes, where conditions condensation are more favorable (Price and Burton 2011:91).

The $\delta^{18}\text{O}$ values in bodily tissues of humans (and all other obligate drinkers) reflect $\delta^{18}\text{O}$ values of a particular source of water consumption; food and atmospheric oxygen influence the $\delta^{18}\text{O}$ value as well, though very insignificantly (Price and Burton 2011:92). In skeletal samples, oxygen isotopes are found in both tooth enamel and bone. As is the case with $\delta^{13}\text{C}$ isotopic values, the isotopic ratios in bone apatite shift gradually if an individual water with a different isotopic composition for a sustained period of time (Ambrose and Krigbaum 2003; Knudson et al. 2004; Laffoon 2012; Price and Burton 2011). Mature tooth enamel, however, does not remodel; the isotopic ratios of tooth enamel remain constant after crown formation is complete (Ambrose and Krigbaum 2003:195). Therefore, $\delta^{18}\text{O}$ values from enamel reflect the $\delta^{18}\text{O}$ values of the water the individual consumed during enamel formation, while $\delta^{18}\text{O}$ values in bone reflect later-life consumption. Further, despite minor dietary variations, individuals will exhibit similar oxygen isotope ratios so long as those individuals are consuming water from isotopically-similar water sources. (Laffoon 2012:59).

Knudson (2009), however, points to the difficulties of performing oxygen isotopic work in the Andes. Knudson (2009:174-6) describes expected $\delta^{18}\text{O}$ values from five zones in Peru and Chile, identified by meters above sea level (masl): (1) *chala*, 0-500 masl; (2) *yunga*, 500-2300 masl; (3) *quechua*, 2300-3500 masl; (4) *suní*, 3500-4000 masl; (5) *puna*, 4000-4800 masl. Only the *chala* and *yunga* zones are implicated in this study. Because of its low altitude and proximity

to the ocean, the *chala* zone exhibits high $\delta^{18}\text{O}$ signatures. Coastal rivers in northern Peru exhibit $\delta^{18}\text{O}$ values between -3.3‰ and -5.7‰, while groundwater feeding nearby springs exhibit slightly more concentrated $\delta^{18}\text{O}$ values (-4.2‰ to -5.1‰) (IAEA/WMO 2006). Because the *yunga* zone is slightly higher above sea level than the *chala*, $\delta^{18}\text{O}$ values should be lower (more negative) in the *yunga* (Knudson 2009:174-5). $\delta^{18}\text{O}$ values in the studied region are particularly linked to altitude; a 2006 joint-study by the International Atomic Energy Agency and World Meteorological Organization (IAEA/WMO 2006) determined the following associations between $\delta^{18}\text{O}$ and masl: 105 masl = -5.1‰; 990 masl = -6.1‰; 1450 masl = -7.1‰; 2020 masl = -8.6‰.

In Knudson's (2009) study, however, oxygen isotope data from archaeological human skeletal samples could not be used to distinguish between even "very different environmental zones." Particularly, Knudson (2009) demonstrated that enamel and bone carbonate oxygen isotope variability from individuals within a site is greater than the variability between sites located in different environmental zones. This variability can likely be attributed to the complex effects of the natural and manmade movement of water in an ecosystem. (*I am doing this quickly but the flow needs a bit of work here – hopefully my edit helps you think about it*)

Particularly, Knudson (2009) attributes the variability in oxygen isotope ratios among skeletal samples from different ecological zones to the movement of water from high-altitude zones to low-altitude zones with little rainfall. In other words, water rapidly moves from high-altitude zones to low-altitude zones before the $\delta^{18}\text{O}$ value properly reflects the changed conditions through evaporation and, because the low-altitude zones experience little rainfall, there is little dilution of the high-altitude water; therefore, the $\delta^{18}\text{O}$ value reflects water at a higher elevation than where it possibly is being consumed. Knudson (2009) also postulated that

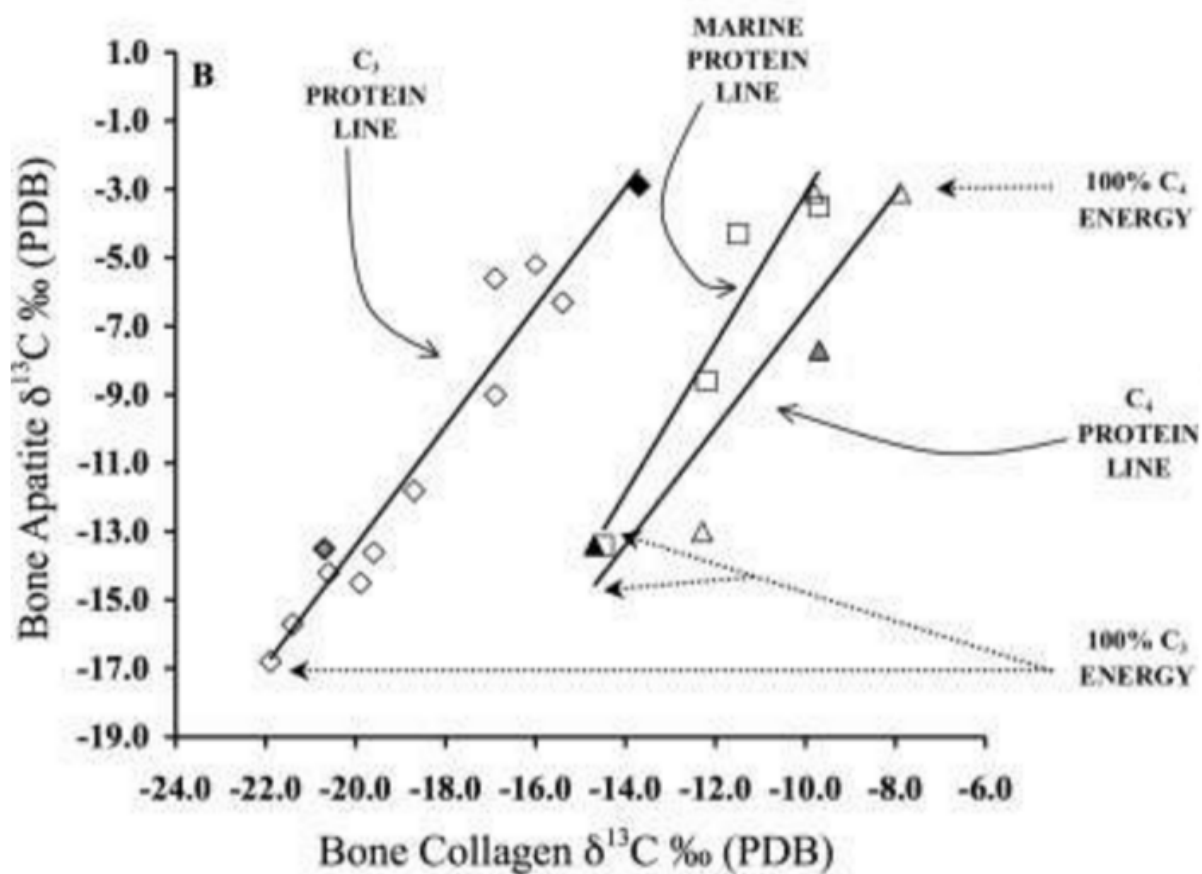
the determined variability could result from cultural practices such as the storage of water and the preparation of widely-consumed beverages. Knudson (2009:185) concluded that “it would be inappropriate to attempt to identify the environmental zone in which an individual lived based on his or her oxygen isotope signature alone.”

4.3.3 *Carbon and Nitrogen Isotopes*

Carbon and nitrogen isotopes are used primarily in the study and reconstruction of diet. The ratio of carbon (^{13}C : ^{12}C) and nitrogen (^{15}N : ^{14}N) isotopes are most readily measured in bone collagen (Ambrose 1991; Larsen et al. 1992; Price and Burton 2011:203). Carbon isotopes are integrated into the body through the food ingested. There are two primary sources of variation in ^{13}C levels in the human diet: (1) the types of plants eaten (i.e., the difference between C_3 or C_4 plants); and (2) the ratio of terrestrial and marine food sources (Larsen et al. 1992; Price and Burton 2011:199). ^{13}C is most abundant in the oceans and certain plants (most notably maize and amaranth in Andean contexts). Ratios of $\delta^{13}\text{C}$ ratios in seawater are higher than in the atmosphere; these differences are evident between plants from land and sea and in the bone collagen of animals feeding on these plants (Ambrose and Krigbaum 2003; Larsen et al. 1992; Price and Burton 2011:93).

A significant correlation exists between apatite ^{13}C and collagen ^{13}C (Kellner and Schoeninger 2007). However, significant overlap exists between $\delta^{13}\text{C}$ values—that is, Kellner and Schoeninger (2007) determined that approximately -6‰ correlates with four distinct diets:

Figure 5. Protein regression and correlation with apatite $\delta^{13}\text{C}\text{‰}$ and collagen $\delta^{13}\text{C}\text{‰}$. Reprinted from Kellner and Schoeninger (2007).



pure C_3 diets, pure C_4 diets, mixed C_3 and C_4 diets, and marine and C_4 diets. But when the protein source can be determined, apatite $\delta^{13}\text{C}$ and collagen $\delta^{13}\text{C}$ yield more useful results. Using three regression lines (one for each protein source: C_3 , C_4 , and marine) provides a means to distinguish between diets with C_3 proteins and those with C_4 proteins. Kellner and Schoeninger (2007) were unable to state that C_4 proteins and marine proteins can be similarly distinguished because there is some overlap between C_4 proteins and marine proteins.

Further, Kellner and Schoeninger (2007) determined that for both C_3 and C_4 proteins, diets predicated on C_4 carbohydrates fall towards the less negative end of the line, while diets

predicated on C₃ carbohydrates fall towards the more negative end of the line. Diets with mixed C₃ and C₄ carbohydrates predictably fall in the middle of the lines.

Kellner and Schoeninger (2007) also showed that animals fed an excess of protein metabolized those amino acids in a manner that leaves behind the carbon isotope, making that isotope available for incorporation in bone mineral along with carbon isotopes drawn from dietary carbohydrates and lipids. Therefore, humans and animals consuming diets disproportionately high in protein may yield carbon isotope values that belie their true consumption.

Plants are classified as C₃ or C₄ plants based on the photosynthetic pathways within the plant that produce distinct carbon isotope ratios (Ambrose and Krigbaum 2003; Larsen et al 1992; Price and Burton 2011). C₄ plants, such as maize, utilize a photosynthetic pathway that metabolizes carbon dioxide by conversion to a four-carbon compound. C₃ plants, on the other hand, use a photosynthetic pathway that converts carbon dioxide to a three-carbon compound. C₃ plants are most common in temperate areas and in tropical forests. The more efficient C₄ pathway is found in plants, grasses, sedges, and grains in warmer, drier climates (Price and Burton 2011). Ninety-five percent of all plants use C₃ photosynthesis. Plants with different photosynthetic pathways will have differing ¹³C and ¹²C ratios. This ratio is expressed as δ¹³C, and represents a “composite dietary signal” (Turner et al. 2010:518) of carbohydrates, fats, and proteins (Schoeninger and DeNiro 1983). Values of δ¹³C from apatite reflect the carbon source of the entire diet (Tykot 2006); δ¹³C from collagen disproportionately reflect the carbon source of protein (Phillips 2008:368). In addition, both C₃- and C₄-consuming animals who are eaten by humans contribute fractionated C₃ and C₄ values to the human diet (Tykot 2006). In both North

and South American populations, carbon isotopic analysis has been used to determine the introduction of maize into the diets (e.g., Tykot 2006; Larsen 2001).

Carbon and nitrogen isotopes can also be used to determine the relative proportion of marine animals in the diet. Marine plants have higher $\delta^{13}\text{C}$ ratios because carbon is dissolved into an inorganic substance in the ocean; because marine animals consume these plants directly or indirectly, the $\delta^{13}\text{C}$ value is elevated from terrestrial species by as much as 7‰ in marine resource consumers (Schoeninger and DeNiro 1983). Unlike marine plants, freshwater plants generally have similar $\delta^{13}\text{C}$ values as terrestrial C_3 plants because their ecosystem is less-complex than the ocean (Tykot 2006). Because the elevated $\delta^{13}\text{C}$ value in marine resource consumers is similar to the increase expected in primarily C_4 consumers, $\delta^{15}\text{N}$ values should be used to distinguish between $\delta^{13}\text{C}$ increases based on C_4 plant consumption and $\delta^{13}\text{C}$ increases derived from marine resource consumption. Human consumers of terrestrial food resources typically exhibit collagen $\delta^{15}\text{N}$ values of about 6–10‰ while consumers of freshwater or marine resources may have $\delta^{15}\text{N}$ values of 15–20‰ (Tykot 2006).

4.4 *Dental Microwear Analysis*

Dental microwear studies can obtain direct data about past behaviors by observing microscopic markings on enamel surfaces (Teaford 2007). Two primary methods exist for conducting dental microwear analysis: Low-Magnification microscopy and Scanning-Electron Microscopy (SEM). Low-magnification microscopy can be done quickly and at relatively little cost, enabling the analysis of larger sample sizes. (Semperebon et al. 2004; Williams and Patterson, 2010). SEM analysis, while more exhaustive, is also more time-consuming, expensive, and subjective (Teaford 2007). Low magnification microscopy has better replicability than SEM,

which has high inter-observer error rates even with the assistance of a computer (Semperebon et al. 2004). Confocal microscopy has also been applied to dental microwear to investigate three-dimensional textural properties of the enamel surface although only two US facilities can conduct these analyses.

Determining the effects specific foods have on teeth, especially when various methods of preparation are involved, is a principal challenge to dental microwear (Teaford 2007). Most foods in the human diet are not hard enough to leave microwear, but the preparation of food can introduce harder materials that can leave microwear (Teaford 2007). And, though the “last supper” effect of dental microwear is often overstated, dental microwear does change as enamel is worn down and new microwear features are made (Teaford 2007).

Microwear analysis is especially useful in determining dietary shifts among human populations. Analyzing human diet can be problematic not only because of food processing, but also because of seasonal, geographic, and annual variation in dietary patterns (Teaford 2007). Despite these challenges, dental microwear is invaluable in assessing large dietary differences (Teaford 2007). Paleodiets have been characterized through the analysis of dental microwear and macrowear, leading to the numerous advances in our understanding of the foods consumed by ancient humans (Schmidt 2010).

4.4.1 Pits and Scratches

Pits and scratches are both formed as a natural result of chewing (Schmidt 2010; Teaford 1991). Pits are microwear features with a length-to-width ratio less than 4:1. Pits form as fracture resistant particles create compression fractures during chewing (Maas 1994; Schmidt 2010:67). Pit-causing agents can be intrinsic or extrinsic to the foods consumed. Intrinsic agents include

bone fragments, some invertebrate exoskeletons, some nutshells, and phytoliths (Strait 1993).

Extrinsic sources are contaminants that adhere to many foods, such as microliths, sand, silt, and clay (Ungar et al. 1995).

Scratches are linear microwear features with a length-to-width ratio exceeding 4:1.

Scratches can be wide or narrow. Wide scratches are more common in individuals pre-agriculture; narrow scratches are more prevalent after agriculture (Schmidt 2010; Teaforde 1991).

Scratches are formed by cusps sliding past each other with little direct opposition. Therefore, relatively soft/tough diets will result in microwear profiles dominated by scratches. Schmidt (2010) suggests that while scratches can also be caused by the same agents that create pits (because the agent is in a different position on the tooth at the time of mastication or involved in a generally softer diet), the size and frequency of different dental wear features are determined by consumed objects of determinable characteristics.

4.5 *Conclusion*

Isotopic and dental micro- and macrowear analyses are complementary in the reconstruction of dietary history. As evidenced by Williams and Holmes (2011, 2012) and Salazar-Garcia (2016) multiple lines of evidence are essential when reconstructing dietary patterns. In the next chapter, the present study is described - keeping in mind the utility of multiple analytical methods to best determine dietary history.

CHAPTER 5: STUDY DESIGN

5.1 *Introduction*

The nature of human diet and methods of food procurement are fundamental aspects of human societies. As discussed above, through the chemical analysis of skeletal remains, it is possible to reconstruct the dietary history of an individual; taken with temporal and demographic data, many fundamental anthropological questions regarding the studied population can be answered. My research focuses on the burial population at the colonial-period sites of La Capilla de Santa Maria de Magdalena de Eten (CSMME) and La Capilla de Nino Serranito (CNS) in northern coastal Peru. My research aims to further contemporary understandings of the outcomes of European contact in Peru and display the one application of dietary reconstruction in understanding past social and cultural conditions.

5.2 *Study Population*

Excavations carried out at CSMME led to the discovery of 256 burials representing the remains of at least 308 individuals. The majority of these burials date to the Early Colonial Period (A.D. 1533-1620). Subsequent excavations revealed burials dating to the Mid- to Late Colonial Period (A.D. 1625-1760) at the site of CNS. Excavations at CNS located 253 burials representing at least 450 individuals. Based on the contextual data regarding these cemeteries, a skeletal collection of the burial population at both CSMME and CNS was selected for isotopic and dental wear analysis.

The 35 selected individuals who were aged were divided into six age classes by Klaus and Tam (2009): Class 1 - 0-4.9 (n=9,0); Class 2 - 5.0-14.9 (n=1,2); Class 3 - 15.0-24.9 (n=1,5); Class 4 - 25.0-34.9; Class 5 - 35.0-44.9 (n=1,5); Class 6 - 45.0+ (n=0,3).^[1] The age of five

selected individuals at CSMME was undetermined. Klaus (2012) performed the aging and sexing of both populations, following Lovejoy et al. (1985). While small sample sizes can be problematic for a number of reasons, previous dental microwear studies have gleaned significant information with only small sample sizes (Gordon 1982).

Relatively little archaeological, palaeobotanical, and anthropological inquiry has been conducted at this site complex (Klaus and Alvarez Calderon, in press). As such, preliminary research at CSMME and CNS must rely on comparative studies within the region to gain greater understanding of the environmental conditions and lifestyle of the indigenous populations inhabiting the Lambayeque Valley near Eten.

CSMME is a young burial population. Of the 235 total burials identified at the site, 180 were under five years of age. Thirty-one were between five and fifteen. Of the seventeen individuals from CSMME selected for this study, ten were five years old or younger, two were adults (20.5 and 35 years), and five were indeterminate. The average age at death at CSMME is 6.04 years, where at CNS the average age of death is 15.5 years (Klaus 2008). High infant mortality rates and increased prevalence of enamel defects are barometers of social, political, economic and ecological factors, especially in regards to infant feeding and care (Fitzgerald et al. 2006:185).

Garland et al. (2015) considered the stress of a subset of individuals from CNS and CSMME through dental histology and identified a higher prevalence of both Wilson bands and enamel hypoplasias at the earlier CNS site than at CSMME (Wilson bands are enamel markers of early childhood stress.) Garland et al. (2015) attributed this to changing epidemiological patterns and differential access to resources through time; the lower prevalence of Wilson bands at the

later CSMME site suggests that the Muchik population may have adapted to Spanish transformations, especially in access to resources and infant feeding and weaning. Garland et al. (2015) noted that the fewer histological characteristics exhibited by the CSMME population may be due to death from stress or disease before hypoplasias and Wilson bands formed. Garland et al. (2015) attributed the young burial population at CSMME to higher birthrates and female fertility, which suggests Muchik adapted to Spanish colonial policies during the Middle to Late Colonial Period.

5.3 *Isotopic Methods*

On a subset of individuals from the burial populations at CSMME (N=18) and CNS (N=17), I conducted dental microwear analysis and referenced existing isotopic data where possible. I also isolated bone and enamel carbonate for $\delta^{18}\text{O}$ and $\delta^{14}\text{C}$ characterization using methods adapted from van der Merwe et al. (1996), Ambrose (1993), and Schoeninger et al. (1989). Enamel from each tooth was removed and pulverized using a mortar and pestle and then soaked for 24-72 hours in a 2% NaOCl/ddH₂O solution. The samples were then centrifuged and rinsed to neutral with ddH₂O and soaked for 2-4 hours in a 0.2% acetic acid solution at 4°C to remove any exogenic carbonates and other contaminants (Garvie-Lok et al. 2004). Isolated carbonate samples were then centrifuged and rinsed to neutral pH with ddH₂O before being freeze-dried and digested in 100% phosphoric acid on an automated prep system at 50°C interfaced with a VG prism mass spectrometer in the Department of Geological Sciences at the University of Florida.

To maximize bone collagen yield while maintaining collagen purity, samples were crushed with an agate mortar and pestle and continually flushed for four hours with a 10:5:1

solution of methanol, chloroform, and ddH₂O in a Soxhlet distillation apparatus to remove lipids, then were air-dried at room temperature for 48 hours. Samples were then transferred to annealed 15 ml glass tubes with Teflon caps and demineralized in 0.5 M HCl at 4°C until translucent, with periodic replacement of HCl. Samples were then treated with a 0.2% KOH solution for 48-72 hours to remove humic contaminants, soaked in 0.5 M HCl for 48 hours at 4 degrees C, and then solubilized in a 0.05 M HCl for 8 hours at 95°C and freeze-dried. Though preparation procedures were completed, these freeze-dried samples have not yet been analyzed using mass spectrometry for logistical reasons, but will be in the near future.

5.4 Dental Microwear Methods

In this study, dental microwear analysis on casts of impressions from selected teeth was conducted by low-magnification stereomicroscopy (LMS). In LMS, are microwear features are counted and classified by type (small, large and puncture pits, and fine, coarse and hyper-coarse scratches) within a 0.4 by 0.4 mm ocular reticle using a low-magnification stereomicroscope (35x) and an external light source (Godfrey et al. 2004; Semprebon et al. 2004; Williams and Patterson 2010; Williams and Geissler, 2014).

LMS has been critiqued for being too subjective. Indeed, Mihlbacher et al. (2012) discovered significant error rates of inter-observer LMS for dental microwear analysis. Mihlbacher et al. (2012) also observed, however, that intra-observer error rates are much lower, though this could be attributed to familiarity with the sample (Williams and Gessler 2014). Further, even though observers using LMS will collect notably different data, overall results will describe the same differences between populations (Mihlbacher et al. (2012).

5.5 Summary

Though this study considers a relatively small sample size that is not necessarily representative of the burial populations at CNS and CSMME, the results gleaned can nonetheless inform additional research of the same populations. In the next chapter, statistical analysis of the aforementioned data are presented, as are the results of this study.

CHAPTER 6: STATISTICAL ANALYSIS AND RESULTS

6.1 *Introduction*

Statistical analysis is important to the accurate interpretation of data. Particularly, LMS dental microwear data must be analyzed statistically to determine the significance of data gathered and to investigate patterns of food consumption. Here, a selection of statistical analyses was run with a number of different groupings. One set included all of the individuals (n=35) without age or sex playing a role. Analyzing the entire sample of individuals led to a better understanding of dental microwear patterns across both populations. Statistics were also run grouped by age and sex. These sets looked at whether any differences in dental microwear were apparent when the data were sorted by those identifying characteristics.

Age Class	CNS	CSMME
1	0	8
2	2	1
3	5	2
4	5	0
5	3	0
6	3	0
?	0	6

Table 1: Total samples by age class and site.

Class 1 = 0-4.9 years of age; Class 2 = 5.0-14.9; Class 3 = 15.0-24.9; Class 4 = 25.0-34.9; Class 5 = 35.0-44.9; Class 6 > 45.0. (Klaus and Tam 2009, Klaus 2012, Lovejoy et al. 1985).

6.2 Results of Dental Microwear Analysis

The results of dental microwear are sorted by three measures: age, sex, and site. First, results are considered by site then both sites are compared. At CNS, all ages and sexes exhibit a higher frequency of fine scratches than any other feature. The CNS population exhibits an average of 8.72 fine scratches per individual, with individuals KGSU230 (20) and KGSU152 (3) forming the upper and lower limits. Small pits are next most prevalent, with an average of 2.06 small pits per individual. KGSU171 (6) sets the upper bound while five individuals set the lower bound at 0.05. Coarse scratches were found more frequently (.97 per individual) than large pits (0.67). Hypercoarse scratches (0.19) and puncture pits (0.06) were found very infrequently.

In the sample population from CNS, there are 6 males and 12 females. When sorted by sex, the following results are shown.

Microwear Feature	Male (n=6)	Female (n=12)
Fine Scratch	9.58	8.29
Coarse Scratch	0.75	1.08
Hypercoarse Scratch	0.00	0.29
Small Pit	1.75	2.21
Large Pit	0.42	0.79
Puncture Pit	0.00	0.08

Table 2. CNS sample population sorted by sex.

Both sexes exhibit a higher frequency of fine scratches than any other feature. Males exhibit a slightly higher frequency of fine scratches than females (9.58 per individual to 8.29). Females exhibit slightly higher frequencies in every other microwear category although the differences are not significant.

Microwear Feature	2	3	4	5	6
Fine Scratch	4	7	10.3	12.83	8
Coarse Scratch	1.25	0.7	1	1	1.17
Hypercoarse Scratch	0	0	0.4	0.5	0
Small Pit	3	1.5	2.1	2.67	1.67
Large Pit	1.5	0.2	0.6	1.17	0.5
Puncture Pit	0	0	0	0.33	0

Table 3. CNS sample population sorted by age class.

When sorted by Age Class, fine scratches remain the most frequent microwear feature at each Age Class. Class 5 (n=3) exhibits the highest frequency of fine scratches, at 12.8 per individual. Class 2 (n=2) exhibits the lowest frequency, at 4 per individual. Fine Scratches increase with Age Class (2=4; 3=7; 4=10.3; 5=12.8) until the transition from Class 5 (12.8) to Class 6 (8). Small pits follow a similar pattern, increasing from Classes 3 to 5 before falling at Class 6.

Class 2 exhibits the highest frequency of coarse scratches (1.25), small pits (3), and large pits (1.5). Large pits is particularly noteworthy, as it is much higher than other classes - Class 5 is second-highest 1.17 and no other class is above .6. In contrast, Class 3 (n=5) exhibits the lowest frequency of three features: coarse scratches (0.7), small pits (1.5), and large pits (.2). None of these lows are extreme. An interesting relationship emerges, however, between Classes 2 and 3. Class 2 posts the highest frequencies for each of these features, while Class 3 presents the lowest. This suggests a shift to tougher, more fibrous foods or the consumption of more processed foods in Age Class 3 than Age Class 2. Age Class 2 includes young and older juveniles and young subadults while Age Class 3 comprises older subadults and young adults suggesting a reliance on foods with hard-object properties decreased toward the end of dental maturation.

Class 5 exhibits the highest frequency of fine scratches (12.8), hypercoarse scratches (0.5), and puncture pits (.33). No other Class exhibited puncture pits, and only Class 4 exhibited hypercoarse scratches (.4). This concentration of hypercoarse scratches and puncture pits suggests that individuals in Age Class 5 (particularly KGSU171 and KGSU 178) consumed more hard objects or used their teeth as tools more frequently than those in other age classes. Adults in Age Class 5 with pronounced frequencies of fine scratches could have had a greater reliance on tough foods, such as leaves or grasses, containing phytoliths or fine particle grit, that were dragged along the enamel surface.

In all microwear features except for coarse scratches, Class 6 exhibits a slight decrease in frequency from Class 5. Further, Class 6 falls more in line with Age Classes 3 and 4 in fine scratches (where Class 3 = 7, Class 4 = 10.3, and Class 6 = 8), small pits (3 = 1.5, 4 = 2.1, 6 =

1.67, and large pits (3 = 0.2, 4 = 0.6, 6 = 0.5). Given the “last supper” effect of dental microwear, these data suggest that Class 6 was eating a diet more similar to Classes 3 and 4 than to Class 5. Age Class 6 includes older adults, which may have consumed foods with fewer phytoliths or fine particle grit than younger adults.

6.3 Cross-tabulation with Chi-Square Test of Significance

Cross-tabulation with Chi-Square Test of Significance was performed to sort individuals into categories based on the microwear traits represented. Two Chi-Square tests were conducted - one on each site. The null hypothesis for each test was: (microwear feature) and (age class) at (site) are independent.

Microwear Feature	CNS (p-value)	CSMME (p-value)
Fine Scratch	0.286	0.712
Coarse Scratch	0.280	0.785
Hypercoarse Scratch	0.366	-
Small Pit	0.680	0.645
Large Pit	0.419	0.056
Puncture Pit	0.258	-

Table 4. Cross-tabulation with Chi-Square results.

At CNS, there were no significant associations between Age Class and Microwear Features, which failed to disprove the null hypothesis for all tested relationships at CNS. At CSMME, one of the four reportable tests was nearly significant - large pits and Age Class returned a p-value of 0.056. While not significant at a 95% confidence level, the near-significance of this relationship suggests that large pits and Age Class at CSMME may not be independent (statistics for Age Class and hypercoarse scratch and Age Class and puncture pit

could not be computed because hypercoarse scratch and puncture pit are constant). This result could, of course, be the product of a relatively small sample size.

6.4 T-Tests

Three T-tests were also conducted on the population to determine the frequencies of different indicators. The first T-test tested the hypothesis that the frequencies of pits or scratches differ significantly by site.

The means of two microwear indicators, and possibly a third, appear to be significantly different between CNS and CSMME. Fine scratches (p-value 0.000; CNS mean: 3.32, CSMME mean: 8.72) and large pits (0.042; CNS: .176, CSMME .667) are significantly different between sites, while difference in the frequency of small pits approaches 5% significance (0.054; CNS: 1.12, CSMME: 2.06). Coarse scratches (0.563), hypercoarse scratches (0.132), and puncture pits (0.963) do not vary significantly between sites.

Independent Samples Test					
		t-test for Equality of Means			
		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of .
					Lower
FineScratch	Equal variances assumed	.000	5.3987	1.2287	2.8989
	Equal variances not assumed	.000	5.3987	1.2030	2.9081
CoarseScratch	Equal variances assumed	.563	.1487	.2546	-.3694
	Equal variances not assumed	.568	.1487	.2573	-.3783
HypercoarseScratch	Equal variances assumed	.132	.1944	.1258	-.0616
	Equal variances not assumed	.130	.1944	.1222	-.0634
SmallPit	Equal variances assumed	.054	.9379	.4699	-.0181
	Equal variances not assumed	.053	.9379	.4606	-.0137
LargePit	Equal variances assumed	.042	.4902	.2316	.0191
	Equal variances not assumed	.042	.4902	.2262	.0197
PuncturePit	Equal variances assumed	.963	-.0033	.0693	-.1443
	Equal variances not assumed	.962	-.0033	.0686	-.1433

Figure 6. First T-Test results.

A second T-test evaluated the hypothesis that, at CNS, the mean frequencies of microwear features vary significantly between males and females. The same test was not run on the CSMME population, as most individuals are subadults and therefore of indeterminate sex.

The mean frequency of each microwear feature does not differ significantly between males and females at CNS; this includes fine scratches (0.853), coarse scratches (0.508), hypercoarse scratches (0.438), small pits (0.654), large pits (0.597), and puncture pits (0.496). Therefore, males and females in the study sample at CNS have similar microwear characteristics. This suggests that there were no differences in diet or dental utility between the sexes at CNS.

Independent Samples Test

		t-test for Equality of Means			
		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of
					Lower
FineScratch	Equal variances assumed	.853	-.4583	2.4263	-5.6019
	Equal variances not assumed	.824	-.4583	2.0207	-4.7516
CoarseScratch	Equal variances assumed	.508	-.2083	.3078	-.8608
	Equal variances not assumed	.510	-.2083	.3052	-.8855
HypercoarseScratch	Equal variances assumed	.438	.2083	.2621	-.3472
	Equal variances not assumed	.569	.2083	.3452	-.6458
SmallPit	Equal variances assumed	.654	.4167	.9122	-1.5170
	Equal variances not assumed	.645	.4167	.8790	-1.5149
LargePit	Equal variances assumed	.597	-.2500	.4635	-1.2326
	Equal variances not assumed	.568	-.2500	.4260	-1.1728
PuncturePit	Equal variances assumed	.496	-.0833	.1197	-.3370
	Equal variances not assumed	.339	-.0833	.0833	-.2667

Figure 7. Second T-Test results.

A third T-Test asked: Are there significant differences in the mean frequencies of pits and scratches between adults and subadults at both sites? This t-test was applied to test for differences between all subadults and adults regardless of site. Of the four testable microwear features, none were significant (fine scratch (0.827); coarse scratch (0.130); small pit (0.616); large pit (0.174)). This tentatively suggests that small children were consuming similar food resources as adults, or food resources that would leave similar microwear patterns.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (2-tailed)
FineScratch	Equal variances assumed	.051	.827	-.669	10	.519
	Equal variances not assumed			-.565	1.267	.656
CoarseScratch	Equal variances assumed	2.722	.130	-.581	10	.574
	Equal variances not assumed			-1.350	9.000	.210
SmallPit	Equal variances assumed	.268	.616	-1.237	10	.244
	Equal variances not assumed			-1.342	1.552	.343
LargePit	Equal variances assumed	2.138	.174	-.605	10	.559
	Equal variances not assumed			-1.406	9.000	.193

Figure 8. Third T-Test results.

6.5 *Associations Between Microwear Results and Isotopic Data*

Dental microwear and stable isotope analysis collectively aid in the reconstruction of dietary life history. Though isotopic analysis is not the main focus of this study, such data are available for some of the studied individuals. It is useful then to consider the microwear results in conjunction with stable isotope data to gain a greater understanding of the dietary history of certain individuals.

Here, two forms of stable isotope analysis are employed: $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$. $\delta^{13}\text{C}$ is useful to compare the dietary prevalence of marine foods, C_4 plants, and animals that ingest C_4 plants with the prevalence of terrestrial animals and C_3 plants (Price and Burton 2011; Tykot 2006). This comparison is significant because 95% of all plants are C_3 plants – however, maize and amaranth are C_4 plants and prevalent in the western Andes. Therefore, (when accounting for other variables) $\delta^{13}\text{C}$ is useful for investigating the reliance on maize or marine foods in an individual's diet (a more holistic understanding of dietary make-up is limited because $\delta^{15}\text{N}$ has not yet been performed on the studied samples) (Tykot 2006).

Burial No.	Tooth No.	Bone No.	Sex	Age Class	$\delta^{13}\text{C}^a$	$\delta^{18}\text{O}^a$	FS	CS	HS	SP	LP	PP
U3-13	173	310B	F	3	-12	-6.1	9.5	0.5	0	1	0.5	0
U2-59	167	299B	F	4	-12	-5.8	6.5	1.5	2	4.5	1.5	0
U3-12	171	309T	F	5	-11.7	-6.3	13	1	1	6	2.5	0
U2-10	151	261B	M	3	-10.7	-3.8	11	1.5	0	2.5	0	0
U3-89	194	337B	M	3	-15.1	-4.7	4	0.5	0	0.5	0.5	0
U3-80	191	334B	M	6	-15.1	-5.8	5	0	0	2.5	0.5	0

Table 5. Summary of individual profiles. ^aValues are expressed permil (‰) relative to the PeeDee Belemite geological standard (vPDB).

In the table above, a few trends are of note (admittedly, these trends are could be merely the product of the small sample size). First, all three females exhibit $\delta^{13}\text{C}$ values ($\delta^{13}\text{C}$ range: -12 to -11.7) that indicate diets predicated on marine resources and C_4 plants or on terrestrial animals consuming C_4 plants (Price and Burton 2011:200; Kellner and Schoeninger 2007). Also, all individuals exhibit at least some pitting, indicative of consuming hard objects or less prepared foods. Further, U3-12 and U2-59 exhibit relatively high instances of small pitting, multiple large pits, and hypercoarse scratches. While the frequency of these microwear features can be attributed to hard object feeding, they may also be the result of using teeth as tools. Finally, given the wide variability in $\delta^{18}\text{O}$ values in Andean populations, the data are inconclusive as to individual mobility but do indicate some variation in consumed water sources, possibly from distinct ecological contexts or possibly due to cultural factors within Lambayeque ($\delta^{18}\text{O}$ range: -6.3 to -3.8) (Knudson 2009).

Dental microwear can be compared to isotopic data to test for correlation between the microwear results and the isotopic data. Figure 9 tests the hypothesis that an increased incidence of fine scratches portends a diet more predicated on the consumption of processed, more fibrous foods by comparing the correlation between fine scratches and $\delta^{13}\text{C}$ values. The Pearson's correlation coefficient between these values is ($r=0.84$). Where r is closer to 1, a strong positive relationship is indicated. Further, the p -value of the slope is 0.0374; at a 95% confidence interval, the slope of the line significantly deviates from horizontal. The level of certainty is influenced by the limited sample size.

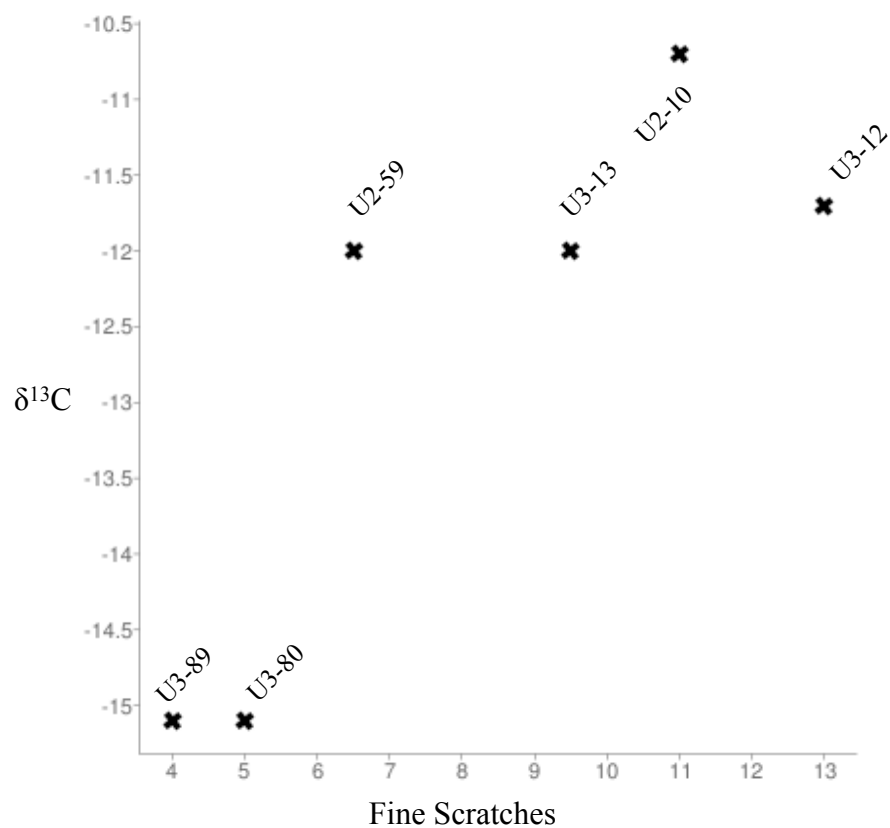


Figure 9. Fine scratches and $\delta^{13}\text{C}$ deviate significantly from horizontal, indicating a strong positive relationship between the variables.

CHAPTER 7: CONCLUSIONS AND FUTURE RESEARCH

7.1 Findings

This study's goal was to better understand the dietary patterns of Early- and Late-Colonial populations on the north coast of Peru. The studied individuals appear to have maintained a similar dietary profile in both periods, suggesting little change across the Spanish colonial period. Wright (1990), among many others, also found little changes in subsistence patterns as a result of Spanish contact. Further, there are no significant differences in the diets when sorted by age or sex. This suggests there was no differential access to food, at least as is isotopically measurable.

There does, however, appear to be significant differences between the foods consumed by all members at each site as a function of time. Where fine scratches and large pits were significantly different between CNS and CSMME, CNS exhibits less fine scratches (CNS mean: 3.32, CSMME mean: 8.72), large pits (CNS: .176, CSMME .667), and small pits (CNS: 1.12, CSMME: 2.06). To the extent that these microwear features capture larger patterns in these two populations, this may suggest that the foods consumed by all members at each site was changed by the influence of Spanish colonial rule. This conclusion is tempered by the age difference between the burial populations at the sites (recall that the studied population from CSMME was all sub-adults, while CNS ranged from sub-adult to adult).

Though only six dietary profiles are indeed a very limited sample size, some questions emerge from collective consideration of the profiles. First, microwear and isotopic data on all three individuals from Age Class 3 suggests a diet predicated on grasses and other fibrous foods. Is this indicative of greater dependence on maize later in the Mid- to Late-Colonial Period? As

the preparation of maize for consumption can involve stone-grinding (and therefore the introduction of pit-causing particles into the diet), perhaps the isotopic data suggesting C₄ consumption combined with microwear data indicating less hard-object feeding suggests maize was consumed in more prepared forms (such as ground into flour or consumed as *chicha*). Therefore, this profiles from Age Class 3 may be indicative of the implementation of food processing techniques more effective at removing grit and other hard objects that the consumption of particular types of food.

Also, all females (from Age Classes 3, 4, and 5) exhibit diets predicated on C₄ or marine foods; two of the three have microwear consistent with varied diets. Does the prevalence of C₄/marine foods again indicate an increased reliance on maize?

Obviously, findings from such a small sample size should be hesitantly applied when drawing broader applications. The aforementioned findings can, however, inform future research on this studied population and others similarly situated. Further, the suggestions made by the six dietary life histories can guide further research into topics of mobility and gender roles in Mid- to Late-Colonial Peru.

7.2 Future Research

The research presented herein only scratches the surface of dietary patterns during the Colonial Period in Peru. This study is valuable if only for its rarity; relatively little research has considered the populations of colonial period South America. Most South American studies focus on the Pre-Contact Period; most Colonial Period studies consider populations in Central or North America.

7.3 Conclusions

Human subsistence patterns are an important aspect of the reconstruction of past human lifeways (e.g., Grine 2007; Turner et al. 2010), and this multi-faceted analysis of a skeletal sample provides continued opportunities for testing and evaluating to confirm or negate previous analyses. Augmenting analyses is an integral component of scientific analysis, which is not always done due to time and funding constraints. This study contributes to better understanding the application of dental microwear analysis in the study of bioarchaeological populations, where only a limited amount of research has been focused on this topic. It also demonstrates the importance of using microwear, histology, and isotopic analyses together to complement each other. By utilizing multiple analytical methods, more specific conclusions about what individuals ate in the past can be made.

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